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The impact of corporate QE on liquidity: evidence from the UK

Lena Boneva,[1] David Elliott,[2] Iryna Kaminska,[3] Oliver Linton,[4] Nick McLaren[5] and Ben Morley[6]

Abstract

Quantitative easing (QE) has become a key component of the monetary policy toolkit since the global financial crisis. However substantial uncertainty remains about the impact of QE on market liquidity. Identifying the impact is particularly challenging due to the potential for reverse causality, because liquidity considerations might affect purchases. To address this challenge, we study the Bank of England's Corporate Bond Purchase Scheme (CBPS), in which the Bank of England purchased £10 billion of sterling corporate bonds via a series of auctions over 2016 and 2017. In particular, we use granular offer-level data from the CBPS auctions to construct proxy measures for the Bank of England's demand for bonds and auction participants' supply of bonds, allowing us to control for any reverse causality from liquidity to purchases. Across a wide range of transaction-based liquidity measures, we find that CBPS purchases improved the liquidity of purchased bonds.

Key words: Quantitative easing, market liquidity, market-making, corporate bonds.

JEL classification: G12, G24, E52, E58.

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(1) Bank of England and CEPR. Email: lena.boneva@bankofengland.co.uk
(2) Bank of England and Imperial College London. Email: david.elliott@bankofengland.co.uk
(3) Bank of England. Email: iryna.kaminska@bankofengland.co.uk
(4) University of Cambridge. Email: obl20@cam.ac.uk
(5) Bank of England. Email: nick.mclaren@bankofengland.co.uk
(6) Ben Morley worked on this paper while at the Bank of England. Email: benmorley1@outlook.com

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Bank of England, Threadneedle Street, London, EC2R 8AH
Email enquiries@bankofengland.co.uk

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1 Introduction

Quantitative easing (QE) has become a key component of the monetary policy toolkit since the global financial crisis. The aim of QE is typically to stimulate nominal spending and therefore increase inflation (Joyce et al., 2011b). But the introduction of a large, relatively price-insensitive buyer has the potential to significantly impact market functioning. Indeed, both policymakers and market participants have raised concerns that central bank asset purchases could lead to a deterioration in market liquidity. For example, in his 2012 Jackson Hole speech, Federal Reserve Chairman Bernanke argued that the Federal Reserve's large-scale asset purchases "could impair the functioning of securities markets" (Bernanke, 2012). Similarly, fund manager PIMCO reported that "the Street's capacity or willingness to provide liquidity has declined" after the ECB began its covered bond purchase programme in 2014 (Financial Times, 2015). Poor liquidity can increase financial stability risks, impede price discovery, and lead to misallocation of resources. Understanding the impact of QE on liquidity is therefore of clear importance to the design of future policy interventions.

However, two factors make it difficult to provide a clear answer to this question. First, the direction of the impact of central bank asset purchases on liquidity is theoretically ambiguous. On the one hand, asset purchases are likely to stimulate trading by inducing portfolio rebalancing. In addition, market participants have argued that the presence of a 'back-stop buyer' makes dealers more willing to hold larger bond inventories, and therefore facilitates market-making. On the other hand, asset purchases lead to a reduction in the quantity of bonds held by private investors, which could damage liquidity by increasing search frictions. Moreover, asset purchases by a relatively price-insensitive central bank might distort price signals, reducing the willingness of market participants to trade. In theory, the net effect of these channels could be positive or negative (Ferdinandusse et al., 2017).

Second, empirical identification of the impact is subject to significant challenges, particularly the possibility of reverse causality. Central bank asset purchases are not randomly assigned across securities, but are instead determined by the central bank's willingness to buy particular assets and market participants' willingness to sell those assets. But both of these might be affected by liquidity considerations, notably expectations for future liquidity. For example, market participants might be more willing to sell bonds that they expect to become less liquid; or the central bank might avoid purchasing bonds that it expects to become less liquid in order to reduce the risk on its own balance sheet. In either case, there would be a problem of reverse causality, with liquidity impacting purchases rather than purchases impacting liquidity. Importantly, this effect could go in either direction, and is likely to affect existing estimates of the impact of QE on liquidity in the literature.

We address these identification challenges by studying a setting — the Bank of England's Corporate Bond Purchase Scheme (CBPS) — where we can estimate the impact of purchases on liquidity while controlling for all potential channels of reverse causality. Across a range of liquidity measures and identification strategies, we find robust evidence that the CBPS purchases improved the liquidity of purchased bonds.

The BoE announced the CBPS in August 2016, as part of a package of monetary stimulus measures following the UK's vote to leave the European Union. The CBPS purchased £10bn of sterling-denominated corporate bonds between September 2016 and April 2017 via a series of auctions. The objective of the purchases was to impart monetary stimulus by lowering corporate bond yields, triggering portfolio rebalancing, and stimulating corporate bond issuance (Bank of England, 2016). But a potential unintended consequence was a reduction in market liquidity. This paper focuses on the impact of the CBPS on liquidity, rather than the overall macroeconomic impact.

Our analysis of the CBPS is based on a novel combination of two granular, proprietary datasets: transaction-level data on the corporate bond market, and offer-level data from the CBPS auctions. We use the transaction-level data to compute a wide range of measures of market liquidity at the level of individual bonds, including simple measures of trading activity such as total weekly trading volume, measures of transaction costs such as the effective spread, and measures of price impact such as the Amihud measure. We then use the auction data to estimate the impact of CBPS purchases on these liquidity measures.

The design of the CBPS and the granularity of the auction data offer novel ways to address the identification challenge described above. In comparison to bilateral purchases (whereby the central bank purchases bonds directly from market participants in the secondary market), the auction design of the CBPS greatly reduces the discretionary nature of purchases.[1] Moreover, the auction dataset provides us with the complete set of information determining purchases. This allows us to construct variables to isolate the impact of liquidity on purchases.

We take two main approaches to identifying the impact of CBPS purchases on liquidity. Under the first approach, we use the auction data to construct proxy variables to directly control for the potential channels of reverse causality from liquidity to purchases. During the auctions, the auction participants submitted offers specifying the bonds that they were willing to sell to the BoE and the spreads (prices) at which they were willing to sell them. These offers can be viewed as expressions of the auction participants' supply of bonds. And ahead of each auction, the BoE set a reserve spread for each bond, i.e. a spread below which any offers would be rejected.[2] The reserve spreads can be viewed as expressions of the BoE's demand for each bond. The CBPS purchases were then determined by the intersection of the BoE's demand and the auction participants' supply. If liquidity impacted CBPS purchases, then this impact must have come via auction participants' supply (as expressed by their offers) or the BoE's demand (as expressed by its reserve spreads). But the granularity of our offer-level dataset allows us to control for both of these, by constructing proxy variables for both the BoE's demand (using the reserve spreads) and auction participants' supply (based on their offers). These demand and supply proxies control for the potential impact of liquidity on purchases, and therefore reduce the magnitude of any reverse causality.

We implement this strategy in an augmented difference-in-differences specification. For each bond and each auction, we estimate several measures of secondary market liquidity for the bond in the week following the auction. We regress these liquidity measures on total CBPS purchases of the bond in the auction, controlling for the BoE's demand and auction participants' supply of the bond, as well as bond and auction fixed effects. In our baseline regressions, the treatment group is bonds that were purchased, and the control group is bonds that received offers in the auction but were not purchased (either because the offer spreads were below the BoE's reserve spreads or because binding purchase limits were hit).

We find that the CBPS purchases significantly improved the liquidity of purchased

[1] The Eurosystem central banks, for example, have generally used bilateral purchases in their asset purchase programmes.

[2] The reserve spreads were based on risk management considerations and the BoE's various purchase targets and limits.

bonds relative to the control group, across a range of liquidity measures. For example, over the week following an auction, a typical purchase size of £5mn was associated with an increase in average trade size of around £0.57mn (compared to an average level of £0.81mn over the sample period), a reduction in the effective bid-ask spread of around 4.3 basis points (compared to an average of 26 basis points), and a reduction in the volatility associated with a £1mn trade of around 3.4 basis points (compared to an average of 26 basis points). These results are consistent with reports from participants in the sterling corporate bond market during the CBPS (Belsham et al., 2017; Financial News, 2017).

It is plausible that the impact on liquidity of the treated bonds spilled over to the control bonds due to investor portfolio rebalancing. In that case, the estimates above would be underestimates of the true effect. In order to obtain estimates that are less likely to be impacted by spillover effects, we repeat the analysis using two additional control groups that are less similar to the treatment group: sterling-denominated investment grade corporate bonds that were not eligible for the CBPS, and euro-denominated bonds issued by issuers who also issued eligible bonds. Using these additional control groups has the advantage that the results are less likely to be impacted by spillover effects; but the disadvantage that we are unable to control for demand and supply (because the bonds in these control groups were not eligible in the auctions). The results using these additional control groups are similar to the results using the benchmark control group.

The results are robust to a number of alternative specifications, including controlling for lagged liquidity using the system GMM estimator of Blundell and Bond (1998), and controlling for unobserved common shocks to purchases and liquidity using the CCE estimator of Pesaran (2006).

Under our second main approach to identification, we run instrumental variables regressions using data on the BoE's purchase limits and historical purchases. Specifically, we instrument current purchases using the proportion of the bond-level purchase limit still available for purchase. This instrument should be relevant because it affected the probability that the bond would be purchased in an auction, by acting as a constraint on purchases. And it should be exogenous, because it was determined mechanically based on amounts outstanding and past purchases, and was not affected by other risk management or liquidity considerations. The IV results are similar to our results using demand and supply proxies: for most liquidity measures, we find that purchases significantly improved liquidity.

Our results suggest that, in this case, the potential negative impact of QE on liquidity did not dominate. On the contrary, CBPS purchases had a significant positive impact on the liquidity of purchased bonds. At the margin, these results should make central banks more willing to implement QE in the future. We do not find any evidence that the liquidity impacts persisted beyond the end of the scheme. Specifically, when we compare the overall change in liquidity of bonds between the start and end of the scheme, we find no evidence that the liquidity of purchased bonds changed systematically relative to sterling bonds that were not purchased.

Related literature

There is a growing literature that assesses the impact of central bank asset purchases on secondary market liquidity. The existing literature focuses primarily on government bond purchases. The direction of the estimated effect varies across studies. Investigating asset purchase programmes in the euro area and UK, Eser and Schwaab (2016), De Pooter et al. (2018) and Steeley (2015) find evidence that government bond purchases improved liquidity. On the other hand, Han and Seneviratne (2018) and Kurosaki et al. (2015) find that sovereign bond purchases in Japan damaged liquidity. Some papers find mixed evidence within a single purchase programme. Christensen and Gillan (2017), Schlepper et al. (2020), Pelizzon et al. (2018) and Iwatsubo and Taishi (2018) find that the direction of the effect varies over time or across liquidity measures.

In comparison, much less is known about how central bank purchases of non-government securities affect market liquidity. Exceptions include Kandrac (2013, 2018), who finds that Federal Reserve purchases of mortgage-backed securities damaged liquidity, and Todorov (2020), who provides evidence that ECB purchases of corporate bonds improved liquidity. The first main contribution of our paper is to fill this gap by assessing the impact of asset purchases on corporate bond liquidity. This has important policy implications, as central banks have increasingly expanded asset purchase programmes to include corporate debt. For example (and in addition to the BoE's CBPS), the ECB introduced its Corporate Sector Purchase Progamme (CSPP) in March 2016, and the Federal Reserve introduced the Primary Market and Secondary Market Corporate Credit Facilities in March 2020 in response to Covid-19. Corporate bonds are typically substantially less liquid than government bonds, making it particularly important to understand the impact of central bank purchases on the liquidity of this asset class.

Our second main contribution is to address an important reverse causality challenge faced by existing papers on this topic. As described above, if the distribution of asset purchases is impacted by liquidity considerations, then existing estimates of the impact of QE on liquidity are likely to be biased. Indeed, Song and Zhu (2014) and Schlepper et al. (2020) both find evidence that central bank purchase decisions are impacted by liquidity. We use granular offer-level data to control for the demand and supply factors that determine the purchases. This should reduce the magnitude of any reverse causality and therefore better identify the causal impact of the purchases on liquidity. To our knowledge, the only existing paper to use offer-level data to estimate the impact of QE auctions is Song and Zhu (2014), which studies the Federal Reserve's purchases of Treasury bonds. However, due to data constraints, that study only uses data on accepted offers. In contrast, we use data on all offers by CBPS auction participants (both rejected and accepted). This allows us to control for dealers' supply using information from the complete supply curve.

The remainder of the paper is structured as follows. Section 2 describes how the CBPS was implemented and discusses the channels through which it might have impacted liquidity. Section 3 describes the auction data and the data on secondary market transactions in the corporate bond market, and explains how we measure liquidity in that market. Section 4 investigates whether the initial announcement of the CBPS had an immediate impact on liquidity. Section 5 describes our two approaches to addressing reverse causality and reports our results regarding the effects of CBPS purchases on liquidity. Section 6 considers whether the CBPS had longer-term impacts on liquidity, and Section 7 concludes.

2 The Corporate Bond Purchase Scheme

2.1 Background to the CBPS

On 4 August 2016, following the UK's vote to leave the European Union, the Bank of England (BoE) announced a package of monetary stimulus measures. This included a reduction in Bank Rate, a new Term Funding Scheme, and an expansion of the BoE's programme of quantitative easing. The expansion of QE included both an increase in government bond purchases and a new Corporate Bond Purchase Scheme (CBPS).

The CBPS was authorised to purchase up to £10 billion of sterling-denominated investment grade corporate bonds over a period of 18 months. The purpose of the CBPS was "to impart monetary stimulus by lowering the yields on corporate bonds, thereby reducing the cost of borrowing for companies directly; by triggering portfolio rebalancing; and by stimulating new issuance of corporate bonds" (Bank of England, 2016, page vii). Liquidity in the corporate bond market was not substantially impaired prior to the purchases, and impacting secondary market liquidity was not an explicit aim of the scheme.[3]

In order to be eligible for purchase, bonds had to be denominated in sterling, rated investment grade, and issued by firms that made "a material contribution to economic activity in the UK" (Bank of England, 2017a). Bonds issued by banks, building societies, insurance companies and other financial sector entities regulated by the BoE or the UK Financial Conduct Authority were ineligible. More detailed eligibility criteria are provided in Bank of England (2017a). A list of eligible bonds was first published on 12 September 2016, and this was updated regularly while purchases were ongoing.

Purchases began on 27 September 2016 and were conducted via auctions (discussed further below). The BoE announced that it had reached the £10bn target on 27 April 2017, at which point purchases ceased. During this seven-month period, the BoE purchased bonds at an average pace of £357mn per week. At the end of the purchase period, the BoE's holdings amounted to around 6% of eligible bonds, by market value.

Since the completion of purchases, the BoE has continued to hold the stock of bonds. In August 2017, the BoE's Monetary Policy Committee (MPC) agreed that the BoE would reinvest cash flows from maturing bonds held under the CBPS back into eligible corporate bonds. The first reinvestment operations took place in September 2019. In March 2020, the BoE announced that it would resume purchases of corporate bonds as part of its response to Covid-19. Further description of the CBPS and the composition of purchases is provided in Belsham et al. (2017).

[3] The BoE also purchased sterling corporate bonds in 2009, with the aim of improving market functioning during the intense financial market stress at the time (Fisher, 2010). The 2009 purchases were of a much smaller scale, with peak holdings of less than £2bn.

2.2 The CBPS auction mechanism

Purchases of corporate bonds were implemented via a series of multi-good reverse auctions. Each eligible bond was assigned to one of nine sectors based on the industrial sector of its issuer. There were three auctions per week, with each auction on a different day. Different sectors were included in different auctions so that each eligible bond was auctioned once per week.

The auction participants were fourteen of the major dealers (market-makers) in the sterling corporate bond market. Dealers submitted offers to sell bonds to the BoE, and were able to submit multiple offers per bond. An offer consisted of a quantity and a price (expressed as a yield spread to the benchmark gilt for that bond), implying that the dealer was willing to sell the offer quantity at a spread less than or equal to the offer spread.

Before each auction, the BoE set a minimum spread (maximum price) for each bond, i.e. a reserve spread. Any offers below the reserve spread would be rejected. The reserve spread was unobserved by auction participants and reflected several factors. First, the BoE sought to purchase a portfolio of bonds that matched the proportion of total outstanding eligible bonds accounted for by different sectors (the 'sector key'). So if a sector was over-represented in the CBPS portfolio relative to the amount in issue, the reserve spreads for bonds in that sector would be increased in order to make offers against bonds in that sector relatively less attractive, and therefore slow down purchases. Similarly, if a sector was under-represented relative to the sector key, the BoE would reduce the reserve spreads for that sector to increase purchases. Second, the reserve spread reflected bond-level, issuer-level and sector-level purchase limits: if the BoE was close to reaching the purchase limits for a bond, it would increase the reserve spread for that bond to reduce the pace of future purchases. Third, the reserve spread reflected market-based and model-based indicators of the risk characteristics of the bond. The BoE reserved the right to adjust the reserve spread on the basis of any other information.

In addition to the sector targets and overall purchase limits, there were also purchase limits within an auction. The BoE would not purchase more than £10mn of a single bond in a single auction. And the total amount that the BoE would purchase in a given auction was determined on the basis of the quantity and quality of offers received.

The purchases were then determined according to the interaction of the offers, reserve spreads, and purchase limits. Offers were ranked in order of attractiveness, taking into account the difference between the offer spread and the reserve spread. Offers would then be accepted in order of attractiveness until the auction purchase target was reached. Offers were allocated on a uniform spread basis, meaning that all successful offers for a bond were allocated at the same spread, with offers at the clearing spread pro-rated if necessary. Further detail on the auction process is available in Bank of England (2017a).

While the main features of the auction process were published, auction participants were able to observe only limited information about the auction outcomes (beyond the outcomes of their own offers). The BoE published weekly data on total corporate bond holdings, with a one-week lag, and a monthly update of sector allocations relative to the sector key. But auction participants were unable to observe reserve spreads, holdings of individual bonds, or purchase limits. Therefore, from the perspective of participants, there was significant uncertainty regarding which of their offers would be accepted and rejected. A participant might submit offers for two different bonds that, from the perspective of the participant, are equally aggressive; but discover that one is accepted and the other is rejected on the basis of unobserved reserve spreads or purchase limits.

The auction mechanism used for the CBPS is in contrast to the manner in which many other central bank asset purchase programmes have been carried out.[4] For example, very few of the asset purchases by the Eurosystem have been implemented via auction. Instead, these programmes have typically been implemented via bilateral purchases in the primary and/or secondary markets. As explained in Section 5, the auction setting provides important advantages for identifying the causal impact of the CBPS on liquidity. This is because it enables us to observe (and therefore control for) the determinants of purchases with much greater granularity, thereby reducing concerns around the endogeneity of purchases.

2.3 The impact of the CBPS on yields, issuance and trading

The spreads of sterling-denominated investment grade corporate bonds fell sharply when the CBPS was announced (Figure 1), indicating that the policy came as a surprise to market participants. By comparing the spreads of eligible sterling bonds to the spreads of dollar and euro bonds issued by the same set of firms, Boneva et al. (2018) estimate that the announcement of the CBPS caused a reduction in eligible bond spreads of at least

[4]The BoE also uses auctions for its government bond QE purchases.

13 basis points. Moreover, analysing the price reaction by bond characteristics, D'Amico and Kaminska (2019) show that the main channels through which market participants believed that the CBPS would affect corporate bond prices were likely to be linked to changes in net supply, rather than confidence or credit risk.

The CBPS appeared to have a significant impact on financing conditions. Gross issuance of sterling non-financial corporate bonds had been falling for several years prior to the introduction of the CBPS, which market participants ascribed to structural developments relating to the investor base (Elliott and Middeldorp, 2016). But sterling issuance increased substantially following the announcement of the CBPS (Figure 2). Market participants argued that the reduction in funding costs caused by the CBPS contributed to this increase in issuance (Belsham et al., 2017; Salmon, 2017).

Our transaction-level dataset (discussed in Section 3) allows us to investigate trading in the sterling corporate bond market during the CBPS purchase period. The sterling corporate bond market is an OTC market intermediated by around fourteen main dealer banks. The main investors in the market are insurance companies and asset managers. Since only dealers could participate directly in the CBPS auctions, if investors wished to sell bonds to the CBPS then they would need to sell them via dealers. This pattern is reflected in the transaction-level data. Figure 3, which is adapted from Mallaburn et al. (2019), shows net secondary market trading volume in eligible bonds by investor type (primary market trades and trades with the CBPS are excluded). Positive numbers indicate net buying volume while negative numbers indicate net selling volume. In the period between the announcement of the CBPS and the start of purchases, insurance companies and asset managers were net buyers of eligible bonds in the secondary market, while dealers were net sellers. But during the purchase period, the main investors had large net selling positions while dealers had large net buying positions, consistent with investors selling bonds to dealers so that dealers could sell the bonds on to the CBPS.[5] The aggregate quantity of bonds sold by insurance companies and asset managers during the purchase period suggests that these investors were the ultimate sellers of around half of the bonds bought by the BoE, with the remainder coming from dealers balance sheets.

[5]This pattern reversed during December 2016. This is likely to reflect two factors. First, the BoE ran fewer auctions during December due to reduced liquidity around the Christmas period. Second, dealers might have been reducing bond inventories ahead of year-end in order to improve regulatory capital and leverage ratios.

2.4 How might the CBPS have impacted liquidity?

Market participants and academics have proposed several mechanisms by which central bank asset purchases could impact liquidity. In theory, the impact on liquidity could be positive or negative.

Stimulating trading: Central bank asset purchases involve market participants selling bonds in exchange for cash. But cash and bonds are imperfect substitutes, so the initial purchases are likely to stimulate further portfolio rebalancing (Joyce et al., 2011a). By stimulating trading, this portfolio rebalancing could also improve liquidity.

Reducing inventory risk: Dealers take risk by holding bonds on their balance sheets as market-making inventory (Stoll, 1978). By providing a predictable source of demand for bonds, asset purchases can reduce the inventory risk faced by dealers. This might make them willing to hold larger inventories and could therefore facilitate market-making (Kandrac, 2018).

Search frictions: Absent new issuance, asset purchases lead to a reduction in the quantity of bonds held by private investors. If there are search frictions, then this could reduce trading by making it more difficult for investors to be matched (Ferdinandusse et al., 2017). And if it becomes more difficult for dealers to source specific bonds in the secondary market, then the costs and risks of market-making could increase, reducing dealers' willingness to intermediate trades (Kandrac, 2018). Moreover, a reduction in the quantity of a bond available for trading by private investors might deter market participation, leading to a thinner market and lower liquidity (Bolton and von Thadden, 1998).

Distorted price signals: Central bank asset purchases typically involve quantity targets, making the central bank relatively price-insensitive in its purchase decisions. Market participants have argued that this can distort price signals and therefore reduce the willingness of investors to trade (Financial Times, 2015).

Market participants in the sterling corporate bond market generally argued that the CBPS improved secondary market liquidity. The key channel that they emphasised was a reduction in inventory risk: investors argued that predictable demand from the CBPS made dealers more willing to hold market-making inventory (Belsham et al., 2017; Financial News, 2017). Over the rest of this paper, we aim to estimate the impact of the CBPS on liquidity more formally.

3 Data

3.1 CBPS auction data

Our auction dataset includes the complete set of information determining CBPS purchases. We observe granular information on each individual offer submitted, including: the identity of the dealer, the ISIN (International Securities Identification Number) of the bond, the offer quantity, the offer spread, the quantity of the offer that was accepted, and the reason the offer was rejected (where applicable). We also observe the BoE's reserve spreads and purchase limits for each bond and each auction.

The dataset covers 82 auctions taking place over the lifetime of the scheme, from 27 September 2016 to 27 April 2017. Over that period, 364 bonds were eligible at some point (issued by 144 issuers), 306 of which were purchased at least once.

Table 1 reports summary statistics for the auction data. For bonds that received at least one offer in a given auction, the average sum of offer quantities was £9.2mn. For bonds that were purchased in a given auction, the average total purchase size was around £5mn. The maximum purchase amount of a single bond in a single auction was £10mn, equal to the purchase limit.

As discussed in Section 2.2, the auction allocations were influenced by reserve spreads set by the BoE. The distribution of reserve spreads is shown in Figure 4 (the chart pools across bonds and auctions). The majority of reserve spreads were below the average market mid spread. However, in some cases the reserve spreads were set substantially higher than quoted market spreads in order to reduce the pace of purchases of particular bonds.

3.2 Liquidity measures

Corporate bond transaction data

To estimate liquidity measures for the corporate bond market, we use the transaction-level 'Zen' dataset maintained by the UK Financial Conduct Authority (FCA). This dataset includes transaction reports for all secondary-market trades by EEA-regulated firms in corporate bonds that are issued by UK firms, and all secondary-market trades by UK-regulated firms in any corporate bond. Since the large majority of the main dealers in the sterling corporate bond market are UK-regulated firms, the dataset should cover the majority of trading in sterling-denominated corporate bonds. And under the assumption that most trading in euro-denominated bonds involves EEA-regulated dealers or investors, the dataset should cover the majority of trading in euro-denominated bonds issued by UK firms.

Each transaction report includes the date, time, ISIN, quantity, price, the identity of the reporting firm, and (in most cases) the identity of their counterparty. The counterparty information allows us to match reports in cases where both counterparties report the trade. We drop trades that are implausibly large or small, or that have implausible reported prices. We also drop trades that occur within one week of the bond's announcement date (trading volumes are much higher in the week after a bond is announced, making this period unrepresentative of normal trading conditions in the bond).[6]

Corporate bond liquidity measures

We estimate market liquidity at the bond level. There is no single accepted liquidity measure for bonds (Schestag et al., 2016). We therefore estimate a wide range of transaction-based liquidity measures drawn from the academic literature. The measures are summarised below and defined in Appendix A. We split the measures into three groups: measures of trading activity, measures of transaction costs, and measures of price impact.

Sterling and euro corporate bonds trade relatively infrequently, with around one trade per day on average in the Zen dataset, so we compute all liquidity measures at weekly

[6] As discussed in Section 2.3, there was an increase in sterling corporate bond issuance after the CBPS was announced. Given that bonds trade most frequently shortly after they are issued, the increase in issuance is likely to have caused an increase in average trading volumes. Since we drop trades around the issuance date, this effect should not affect our analysis.

frequency. We also winsorise several liquidity measures at 2.5% and 97.5% to reduce the impact of outliers.[7] Summary statistics for all the liquidity measures are provided in Table 2 for the sample period January 2016 to December 2017.

Measures of trading activity. We compute four simple measures of trading activity: weekly number of trades (COUNT), weekly sterling trading volume (VOLUME), average trade size (SIZE), and weekly number of 'large' trades (LARGE).[8] For these measures, higher numbers are likely to indicate better liquidity. As reported in Table 2, the average trade size for CBPS-eligible bonds is around £0.81mn, and eligible bonds trade on average around 4.4 times per week. As shown in Figure 5, the measures of trading activity exhibit substantial volatility but no clear trend over the sample period. The measures of trading activity are cruder than the measures of transaction costs and price impact. But their simplicity means that they can be estimated more reliably than the other measures, with fewer missing observations.

Measures of transaction costs. We compute two measures of transaction costs: the effective spread (SPREAD), and the Roll (1984) measure. These can be interpreted as transaction-based estimates of the bid-ask spread. For these measures, higher numbers indicate worse liquidity. These measures suggest that the average transaction-based bid-ask spread of eligible bonds is between 25 and 40 basis points (Table 2). As shown in Figure 6, both of these measures indicate that the liquidity of eligible bonds and ineligible sterling investment grade bonds improved during the period in which CBPS purchases occurred.

Measures of price impact. Finally we compute two measures of price impact: the Amihud (2002) measure, and a simple implementation of the volatility-over-volume (VOV) measure of Fong et al. (2017). For these measures, higher numbers indicate worse liquidity. The Amihud measure indicates that, on average, a £1mn trade moves the price of eligible bonds by around 83 basis points. Meanwhile, volatility-over-volume suggests that an increase in trading volume of £1mn increases price volatility by around 26 basis points (Table 2). As for the measures of transaction costs, both measures of price impact suggest

[7] We winsorise SPREAD, ROLL, AMIHUD and VOV.

[8] We define a large trade to be one that is greater than £2mn, which is approximately the 90th percentile of the trade size distribution.

that the liquidity of eligible bonds and ineligible sterling bonds improved substantially over the CBPS purchase period (Figure 6).

While many of these measures indicate that liquidity in the sterling corporate bond market improved as CBPS purchases took place, we cannot conclude that this improvement was driven by the CBPS, because multiple other factors are likely to have also impacted corporate bond liquidity during this period. For example, broader financial market sentiment during this period was boosted by an improving outlook for global economic growth, as well as accommodative monetary policy from both the European Central Bank and the Bank of England (Bank of England, 2017c). In addition, the improvement in liquidity might have been part of a longer-run trend of adjustment to regulation. The introduction of post-crisis regulation such as the leverage ratio is likely to have contributed to reductions in fixed income liquidity in the years before the launch of the CBPS (Bicu-Lieb et al., 2020). However, over 2017, dealers were reported to have improved their balance sheet optimization in response to these regulations, resulting in improvements in the liquidity of fixed income markets, including corporate bonds (Bank of England, 2017b).

These factors imply that we cannot simply interpret time series trends in corporate bond liquidity as being caused by the CBPS. We therefore exploit weekly cross-sectional variation across bonds to identify the impact of the CBPS purchases, as explained in Section 5.

4 Announcement effects

Before estimating the impact of the purchases on liquidity, we investigate whether the announcement of the CBPS itself had a direct impact on liquidity. Specifically, we estimate the following cross-sectional regression:

$$\Delta \text{Liquidity}_b = \mu + \beta \text{Eligible}_b + \phi' \text{Controls}_b + \epsilon_b, \tag{1}$$

where $\Delta\text{Liquidity}_b$ is the liquidity of bond b in the calendar week after the announcement (8 – 12 August) minus liquidity in the calendar week before the announcement (25 – 29 July); and Controls_b is a set of bond-level variables measured prior to the announcement:

amount outstanding, credit rating, residual maturity, residual maturity squared, industry fixed effects, yield spread to the reference government bond, and amount outstanding of gilts with a similar residual maturity (within two years).

The variable of interest is Eligible_b, which is an indicator variable equal to one for bonds that were eligible for purchase by the CBPS and zero otherwise.[9] We consider two control groups: sterling-denominated investment grade bonds that were never eligible (bonds issued by banks and insurance companies are excluded), and euro-denominated bonds issued by firms who had also issued eligible bonds.

The results are summarised in Table 3. There is evidence of significantly increased trading activity in eligible bonds relative to euro-denominated bonds. This might have reflected investor positioning ahead of the purchase period, as illustrated in Figure 3. However the estimated coefficients on the transaction cost and price impact measures are statistically insignificant in most cases, suggesting that the initial announcement did not cause an immediate change in the costs of trading.

5 Impact of CBPS purchases on liquidity

5.1 Identification

We now estimate the impact of the CBPS purchases on liquidity. In doing so, we address a general identification challenge faced by any study of the impact of central bank asset purchases on liquidity, deriving from the fact that asset purchases are not randomly assigned across bonds. Suppose that liquidity is determined by the following equation:

$$L_{bt} = \alpha_b + \mu_t + \beta P_{bt} + \delta^{\mathsf{T}} Z_{bt} + e_{bt}, \tag{2}$$

where L_{bt} denotes the liquidity of bond b in period t, P_{bt} denotes asset purchases, and Z_{bt} is a vector of other variables that impact liquidity. Importantly, Z_{bt} could include variables that are observed by market participants but not by the econometrician, notably market participants' *expectations* for liquidity. The identification challenge arises if purchases are also affected by these variables: for example, market participants might be more willing to

[9]Although the list of eligible bonds was not published at the time of the announcement, the main eligibility criteria were published, and Boneva et al. (2018) show that the spreads of eligible bonds fell significantly more than the spreads of ineligible sterling bonds after the announcement, indicating that investors were to a large extent able to predict which bonds would be eligible.

sell bonds that they expect to become less liquid; the central bank might avoid purchasing bonds that it expects to become less liquid in order to protect its own balance sheet; or the central bank might focus puchases on less liquid bonds in an attempt to improve the liquidity of those bonds. Indeed, Song and Zhu (2014) and Schlepper et al. (2020) both find evidence that central bank asset purchase decisions are impacted by liquidity. In any of these cases, there would be a problem of reverse causality, with liquidity impacting purchases rather than purchases impacting liquidity, and so simply regressing liquidity L_{bt} on purchases P_{bt} would result in a biased estimate of β. Importantly, this effect could go in either direction.

The design of the CBPS and the granularity of our dataset offer novel ways to address this challenge. In comparison to bilateral purchases, the auction design of the CBPS greatly reduces the discretionary nature of purchases. Moreover, the auction dataset provides us with the complete set of information determining purchases — including auction participants' offers and the BoE's reserve spreads and purchase limits. This allows us to construct variables to isolate the impact of liquidity on purchases.

We take two main approaches, described in detail below. First, we use data on auction offers and reserve spreads to construct variables to directly control for the potential channels of reverse causality from liquidity to purchases (Section 5.2). Second, we use data on purchase limits and historical purchases to construct an instrument for current purchases (Section 5.3).

5.2 Controlling for supply and demand factors

Specification

As explained above, CBPS purchases were not randomly assigned across bonds, but were instead determined by the intersection of auction participants' supply and the BoE's demand. Both of these might have been impacted by liquidity considerations, raising the possiblity of reverse causality. However, given that purchases were made via auctions, we are able to observe and therefore control for granular measures of both the supply and demand factors determining purchases. We observe all of the individual offers by market participants to sell bonds to the BoE, and can therefore use this information to construct bond-level proxies for the strength of auction participants' supply in each auction. We construct two such proxies: one based on quantity (the total quantity of the bond offered in the auction) and one based on price (the average spread between the offer yields in the auction and the offer yield quoted in the market). Similarly, we use the BoE's bond-level reserve spread as a proxy to control for the strength of its demand for the bond. By including these demand and supply proxies in our regressions, we are able to directly control for the two potential channels of reverse causality. This argument is set out formally in Appendix B.

Specifically, we run staggered difference-in-differences regressions at the bond-auction level. Each regression uses data for bonds in a treatment group and bonds in a control group, and takes the following form:

$$\text{Liquidity}_{bt} = \alpha_b + \mu_t + \beta\text{PurchasedAmount}_{bt} + \kappa X_{bt}^{\text{Demand}} + \delta' X_{bt}^{\text{Supply}} + \epsilon_{bt}, \quad (3)$$

where:

- Liquidity_{bt} is a measure of secondary market liquidity for bond b in the week starting immediately after auction t.
- α_b and μ_t are bond and auction fixed effects.
- $\text{PurchasedAmount}_{bt}$ is the total nominal quantity of bond b purchased in auction t, denominated in sterling millions.
- X_{bt}^{Demand} is the BoE's reserve spread for bond b in auction t, which we use as a proxy variable for the BoE's demand for the bond.
- X_{bt}^{Supply} is a vector of two variables summarising the supply by auction participants of bond b in auction t: the total nominal quantity offered in the auction (summed across all auction participants); and the volume-weighted average spread between auction participants' offer yields and the average offer yield quoted in the secondary market.

The coefficient of interest is β. This provides an estimate of the impact of CBPS purchases on the liquidity of purchased bonds in the week following the auction.

We run separate regressions for different liquidity measures and different control groups (discussed below). In each case, the treatment group consists of bonds for which $\text{PurchasedAmount}_{bt}$ is greater than zero, i.e. bonds that were purchased in auction t.

Note that bonds can be treated multiple times because they can be purchased in multiple auctions. Standard errors are double-clustered at the bond and auction levels.

Control groups

For robustness, we consider four different control groups. Our benchmark control group (**Offer**) consists of bonds that were eligible in auction t and received offers, but were not purchased (either because the offer spreads were below the reserve spread or because purchase limits were reached). Note that bonds frequently move between the treatment group and this control group depending on whether they have offers accepted. That is, treatment status is determined within each auction, and bonds in the treatment group on one date are likely to be in the control group on other dates. The identifying assumption is that — in the absence of purchases, and conditional on demand and supply — the liquidity of purchased bonds would have moved in line with the liquidity of this control group: the 'parallel trends' assumption. This is very plausible, given that the BoE's eligibility criteria ensured that the bonds in the treatment and control groups had similar characteristics in terms of credit rating, sector, and geographical focus.[10]

Our second control group (**Limit**) is a subset of the first. It consists of bonds that were eligible in auction t and received offers in which the offer spread was greater than the reserve spread (that is, attractive to the BoE), but were not purchased because auction or issuer purchase limits were reached within the auction. Given that these offers were at attractive prices, it would have been particularly difficult for auction participants to predict that they would be rejected. Including this control group acts as a robustness test against the possibility that auction participants were using sophisticated bidding strategies that are not well approximated by our two proxy variables for supply.

The bonds in the Offer and Limit control groups are likely to be close substitutes to the bonds in the treatment group. This has the advantage that the parallel trends assumption is likely to hold. However, it also raises the possibility that the impact of purchases on the treatment group 'spills over' to the control group: investors who have sold bonds to the CBPS might rebalance their portfolios into bonds in the control group, and this might mean that the CBPS purchases also indirectly impact the liquidity of

[10]The parallel trends assumption cannot easily be visually inspected for this control group, given that bonds frequently move between the treatment and control groups.

control bonds.[11] In order to obtain estimates that are less likely to be impacted by these spillover effects, we repeat the analysis using two control groups that are less similar to the treatment group: sterling-denominated investment grade corporate bonds that were never eligible for the CBPS (**Sterling**),[12] and euro-denominated bonds issued by issuers who had also issued eligible bonds (**Euro**).

We can use Figures 5 and 6 to assess how well the parallel trends assumption holds for these two additional control groups by observing trends in the liquidity measures prior to the start of CBPS purchases. Over the pre-CBPS period, most of the liquidity measures for eligible bonds and ineligible sterling bonds move relatively closely together, providing support for the parallel trends assumption. The figures provide less support for the parallel trends assumption in the case of the euro control group, which might reflect differences in the investor base.

Sample construction

Eligible bonds were auctioned once per week, but different bonds were auctioned on different weekdays depending on the sector of the issuer. So for eligible bonds (i.e. the treatment group and the first two control groups), the regressions only use data from auctions in which the bond was eligible. And we estimate the liquidity measures using trades in the week starting on the day that the bond was auctioned, excluding the period on the auction day before the close of the auction.

The Sterling and Euro control groups consist of ineligible bonds. We match each of these bonds to auctions based on the sector of the issuer. We then estimate the liquidity measures for these bonds in the same way as for eligible bonds, i.e. using trades in the week starting on the day of the auction to which the bond was matched, excluding trades before the close of the auction. Since these bonds are ineligible, purchased amount is always equal to zero, and the demand and supply proxies are unobserved and therefore excluded from the regressions.

[11] Note that spillover effects on control bonds might be expected to be in the same direction as the direct effect on treated bonds, meaning that our difference-in-differences estimates might be expected to be underestimates of the true effect.

[12] Bonds issued by banks and insurance companies are excluded.

Results

Our baseline results are summarised in Table 4. We run regressions for eight liquidity measures and four control groups, resulting in a total of 32 regressions.

The results for the Offer control group are shown in Panel A. We find that trading activity increased after CBPS purchases. Specifically, in response to a typical purchase of £5mn, the number of weekly trades (COUNT) increases by around 1.4 (compared to an average of 4.4 for eligible bonds over the sample period), weekly trading volume increases by around £3.7mn (compared to an average of £3.5mn), the average trade size increases by around £0.57mn (compared to an average of £0.81mn), and the number of large trades (trades larger than £2mn) increases by around 0.46 (compared to an average of 0.45).

The measures of transaction costs also suggest that CBPS purchases improved liquidity. A typical purchase of £5mn is associated with a reduction in the effective spread of around 4.3 basis points (compared to an average of 26 basis points), and a reduction in the Roll measure of the bid-ask spread of 1.8 basis points (compared to an average of 41 basis points). We also find that the CBPS reduced the price impact of trades. Following a £5mn purchase, the Amihud measure falls by 4.1 basis points (compared to an average of 83 basis points), and the volatility-over-volume measure falls by around 3.4 basis points (compared to an average of 26 basis points).

The results using the other three control groups (Panels B, C and D) are very similar. Overall these results provide robust evidence that the CBPS purchases improved the liquidity of purchased bonds. This is consistent with reports from market participants in the sterling corporate bond market. The key channel that they emphasised was a reduction in inventory risk: predictable demand from the CBPS made dealers more willing to hold market-making inventory and intermediate trades (Belsham et al., 2017; Financial News, 2017).

Robustness tests

In Table 5, we include the lagged dependent variable (i.e. lagged liquidity) as an additional control variable, using the system GMM estimator of Blundell and Bond (1998). The results are similar to our baseline results. Statistical significance is reduced in a small number of regressions, which could reflect a reduction in efficiency arising from the instrumental variables approach. The coefficient on lagged liquidity is generally relatively small.

We perform three further robustness tests. First, we re-estimate the baseline regressions for the Offer and Limit control groups, but exclude the proxy variables for demand and supply. Second, we scale the treatment variable (purchased amount) by amount outstanding, to allow for the possibility that the effect of purchases depends on the quantity of the bond in issue. Third, we repeat the analysis using the common correlated effects (CCE) estimator of Pesaran (2006), which controls for unobserved common shocks to both purchases and liquidity. The results from all of these robustness tests (available in Appendix C) are similar to our baseline results.

5.3 Instrumental variables approach

Our second identification strategy follows an instrumental variables approach. We drop the supply and demand proxies to give the following equation of interest:

$$\text{Liquidity}_{bt} = \alpha_b + \mu_t + \beta \text{PurchasedAmount}_{bt} + \epsilon_{bt}. \tag{4}$$

We then instrument $\text{PurchasedAmount}_{bt}$ using the proportion of the bond-level purchase limit still available for purchase; that is:

$$\frac{\text{PurchaseLimit}_{bt} - \text{CurrentHolding}_{bt}}{\text{PurchaseLimit}_{bt}}$$

This instrument should be relevant because it affected the probability that bond b would be purchased in auction t, by acting as a constraint on purchases. And it should be exogenous, because it was determined mechanically based on amounts outstanding and past purchases, and was not affected by other risk management or liquidity considerations.

We consider three control groups: bonds that were eligible in auction t but were not purchased (either because they received no offers or because the offers were not accepted), plus the Offer and Limit control groups described in Section 5.2.

The IV results are summarised in Table 6. The instrument is strong, with a first-stage F-statistic above 60 in all regressions. The second-stage results are similar to the results using the supply and demand proxies. For most liquidity measures, we find that purchases improved liquidity, although for some liquidity measures there is a reduction in statistical significance.

5.4 Heterogeneous effects

In this subsection we investigate whether the effects estimated in Section 5.2 varied across bonds or across time.

Variation across bonds

In recent years, market participants have argued that there has been a reduction in the liquidity of corporate bonds in general (Committee on the Global Financial System, 2014) and sterling corporate bonds in particular (Elliott and Middeldorp, 2016; Financial Conduct Authority, 2017). Market participants and policymakers have raised the concern that the reduction in liquidity has been larger for less liquid bonds: that is, that there has been a 'bifurcation' in liquidity across bonds (Dudley, 2016). We therefore investigate how the impact of the CBPS varied across bonds according to their liquidity prior to the scheme: did the CBPS contribute to or lean against any bifurcation in liquidity?

To address this question, we introduce interaction terms to extend our baseline specification to the following regression:

$$
\begin{aligned}
\text{Liquidity}_{bt} = \; & \alpha_b + \mu_t + \beta \text{PurchasedAmount}_{bt} \\
& + \phi \left(\text{PurchasedAmount}_{bt} \times \text{Pre-CBPS liquidity}_b \right) \\
& + \kappa X_{bt}^{\text{Demand}} \\
& + \gamma \left(X_{bt}^{\text{Demand}} \times \text{Pre-CBPS liquidity}_b \right) \\
& + \delta' X_{bt}^{\text{Supply}} \\
& + \psi' \left(X_{bt}^{\text{Supply}} \times \text{Pre-CBPS liquidity}_b \right) + \epsilon_{bt},
\end{aligned}
\tag{5}
$$

where Pre-CBPS liquidity$_b$ is defined as the level of liquidity for bond b in the week before the announcement of the CBPS (and demeaned across bonds).

The coefficient of interest is ϕ, which provides an estimate of how the impact of CBPS purchases on liquidity varied with the level of pre-CBPS liquidity.

The results for this regression are summarised in Table 7. For all dependent variables, positive coefficients on the interaction term would indicate that CBPS purchases improved liquidity more for bonds that were already more liquid (consistent with bifurcation), while negative coefficients would indicate that the CBPS had more beneficial impacts on the liquidity of less liquid bonds. We find that almost all estimated coefficients on the interaction between purchases and pre-CBPS liquidity are small and statistically insignificant. Overall, these results do not indicate that the impact of the CBPS differed systematically across purchased bonds.

Variation across time

The strength of the channels from asset purchases to liquidity discussed in Section 2.4 is likely to depend on time-varying factors such as the expected time until completion of the scheme. We therefore estimate whether the size of the impact of purchases on liquidity established in Section 5.2 varied over the lifetime of the scheme. To that end, we estimate the following regression:

$$
\begin{aligned}
\text{Liquidity}_{bt} \quad = \quad & \alpha_b + \mu_t + \beta \text{PurchasedAmount}_{bt} \\
& + \phi \left(\text{PurchasedAmount}_{bt} \times \text{Trend}_t \right) \\
& + \kappa X_{bt}^{\text{Demand}} \\
& + \gamma \left(X_{bt}^{\text{Demand}} \times \text{Trend}_t \right) \\
& + \delta' X_{bt}^{\text{Supply}} \\
& + \psi' \left(X_{bt}^{\text{Supply}} \times \text{Trend}_t \right) + \epsilon_{bt},
\end{aligned} \tag{6}
$$

where Trend_t is a linear time trend variable at weekly frequency (defined to be zero at the midpoint of the purchase period).

The results are summarised in Table 8. For the measures of trading activity (COUNT, VOLUME, SIZE, LARGE), the estimated coefficient on the interaction between purchased amount and the time trend is generally negative and significant. This indicates that the positive impact of CBPS purchases on trading activity decreased over the purchase period. For the other liquidity measures, the estimated coefficient on the interaction term is statistically insignificant for most control groups.

The reduced impact on trading activity might have reflected a weakening in the inventory risk channel over the course of the scheme. As the CBPS approached its £10bn purchase target, the future time period over which dealers would be able to sell excess inventory to the CBPS reduced. Therefore the reduction in inventory risk associated with the CBPS might have dissipated, potentially reducing the positive impact of the CBPS on dealers' willingness to intermediate trades.

6 Stock effects of CBPS on liquidity

The results in Section 5 indicate that CBPS purchases improved the liquidity of bonds in the week following the purchase. In other words — and following the terminology of D'Amico and King (2013) — we find that the CBPS had 'flow effects' on bond liquidity. We now turn to the question of whether the purchases also had longer-lasting 'stock effects' on liquidity by comparing how the liquidity of bonds changed between the start and end of purchases.

Specifically, we run cross-sectional regressions of the form:

$$\Delta\text{Liquidity}_b = \mu + \beta\text{TotalPuchasedAmount}_b + \phi'\text{Controls}_b + \epsilon_b, \qquad (7)$$

where $\Delta\text{Liquidity}_b$ is the liquidity of bond b in the week after purchases were completed minus liquidity in the week before the CBPS was announced. The variable of interest is $\text{TotalPurchasedAmount}_b$, which is defined as the total quantity of bond b purchased by the CBPS over the entire purchase period. We include several bond-specific control variables measured just before the announcement of the CBPS: amount outstanding, credit rating, residual maturity, residual maturity squared, industry fixed effects, yield spread to reference gilt, and amount outstanding of gilts with a similar residual maturity.[13] We also include bond-level control variables computed over the duration of the scheme: change in credit rating, change in amount outstanding of gilts with a similar residual maturity, and BoE QE purchases of gilts with a similar maturity.

The treatment group is bonds that were purchased during the CBPS period. We consider two control groups: bonds that were eligible but never purchased, and ineligible sterling investment grade corporate bonds (bonds issued by banks and insurance companies are excluded).

The results are shown in Table 9. In almost all cases, the estimated impact of total purchases on liquidity is statistically insignificant. This suggests that the liquidity effects of the CBPS did not extend beyond the active phase of purchases. That is, although the CBPS had beneficial 'flow effects' on bond liquidity, there were no 'stock effects'

[13] Specifically, gilts with a residual maturity within two years of the residual maturity of bond b.

arising from the BoE's total holdings of corporate bonds. This is consistent with the inventory risk channel discussed in Section 2.4: the CBPS might have supported liquidity by providing a committed buyer to the market, but this impact did not persist once CBPS purchases were completed.

In this respect, our findings are in line with Christensen and Gillan (2017), who study the impact of the Federal Reserve's purchases of TIPS on liquidity premia during QE2. They find that TIPS liquidity premia fell during the program, but that the effects dissipated towards the end of the purchases. They conclude that, although QE can improve financial market functioning through a liquidity channel, the liquidity effects are only sustained as long as purchases are ongoing and expected to continue.

7 Discussion and conclusions

Identifying the impact of central bank asset purchases on liquidity is plagued with endogeneity concerns, particularly the possibility of reverse causality. For example, if the central bank aims to purchase more or less liquid bonds, then liquidity will be impacting purchases as well as purchases impacting liquidity. In order to address this identification challenge, we study the Bank of England's Corporate Bond Purchase Scheme (CBPS), in which the BoE purchased £10bn of sterling corporate bonds via a series of auctions over 2016 and 2017. To estimate the impact of the purchases on liquidity, we create a novel dataset by combining transaction-level data from the corporate bond market with proprietary offer-level data from the CBPS auctions.

The auction design of the CBPS and the granularity of our auction dataset offer novel ways to alleviate the reverse causality problem. In particular, we are able to control for the impact of liquidity on purchases by constructing proxy variables for auction participants' supply of bonds (based on their offers in the auctions) and the BoE's demand for bonds (based on the reserve prices that it set ahead of the auctions).

We find that CBPS purchases improved the liquidity of purchased bonds in the week following the purchase. This result is robust across a range of transaction-based liquidity measures, control groups, and identification strategies. However, when we compare the overall change in liquidity between the start and end of the scheme, we find no evidence that the liquidity of purchased bonds changed systematically compared to sterling bonds that were not purchased.

The fact that we observe positive short-run effects on liquidity, but do not observe significant long-run effects, could reflect the relatively small size of the scheme. Theoretically, the positive channels through which QE might impact liquidity — namely by stimulating trading and reducing inventory risk — could operate even for small purchases. Meanwhile, the potential negative channels — increased search frictions and distorted price signals — are more likely to become important when the stock of purchases is relatively large. This possibility would reconcile our results with those of Kandrac (2018), who finds that the Federal Reserve's (much larger) purchases of mortgage-backed securities had negative impacts on liquidity.

Our results have important policy implications. Policymakers and market participants have repeatedly raised concerns that asset purchases could have the unintended consequence of causing a deterioration in liquidity. Our results provide evidence that, in the case of the CBPS, the purchases caused an improvement, rather than a deterioration, in liquidity. At the margin, this should make central banks more willing to implement QE in the future. While our empirical tests are not designed to sharply differentiate between the different channels through which asset purchases can impact liquidity, the results appear consistent with a scenario in which the purchases provided dealers with confidence that they could sell bonds to the BoE if needed, and thereby increased dealers' willingness to hold inventory and intermediate trades. This channel might have been strengthened by the fact that the purchases were implemented via auction, which increased transparency and gave dealers more influence over which bonds would be bought, compared to an operational design in which the central bank purchases bonds bilaterally.

The CBPS is a monetary policy tool, and did not have an explicit objective of improving market liquidity. However, since the financial crisis, policymakers and academics have paid increased attention to the question of whether, and under what conditions, the central bank should act as 'market-maker of last resort' (MMLR) in markets suffering a reduction in liquidity (BIS, 2014). The results in this paper indicate that asset purchases conducted via auction can improve the liquidity of corporate bond markets and therefore have implications for the design of any future MMLR operations.

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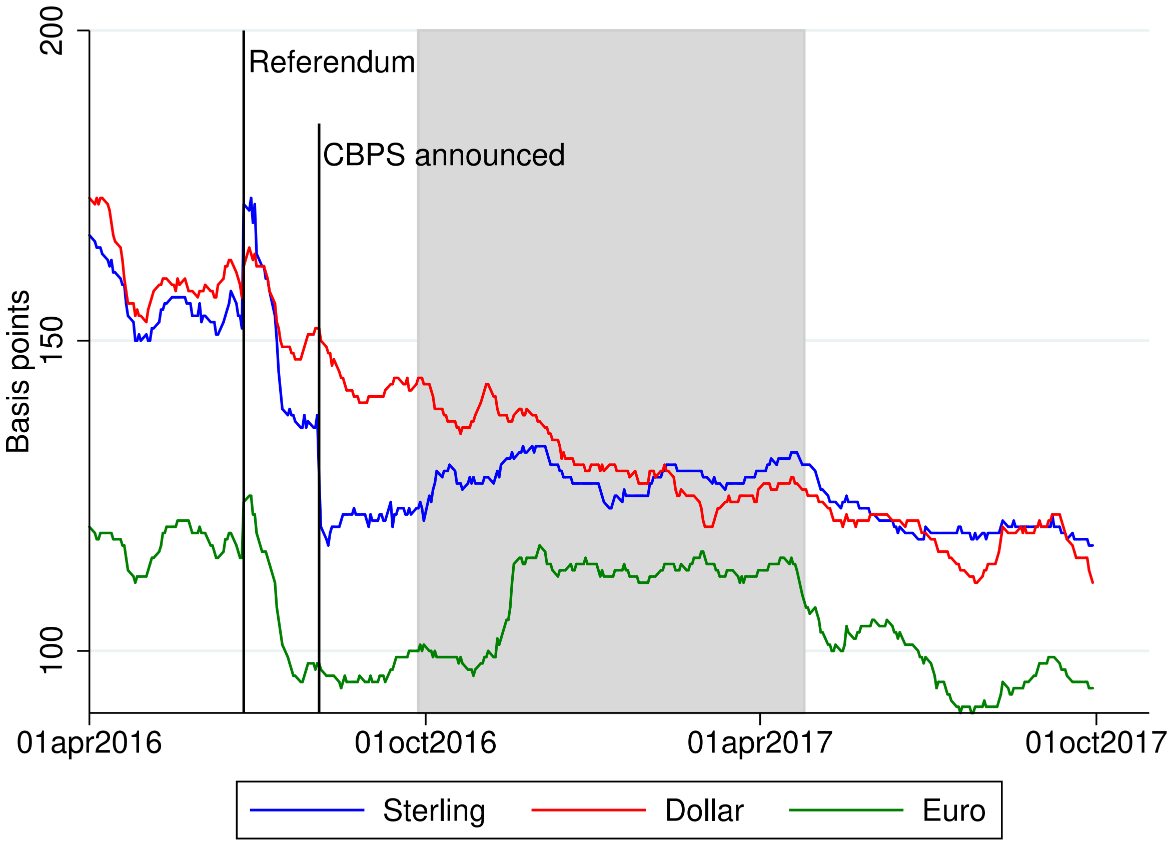
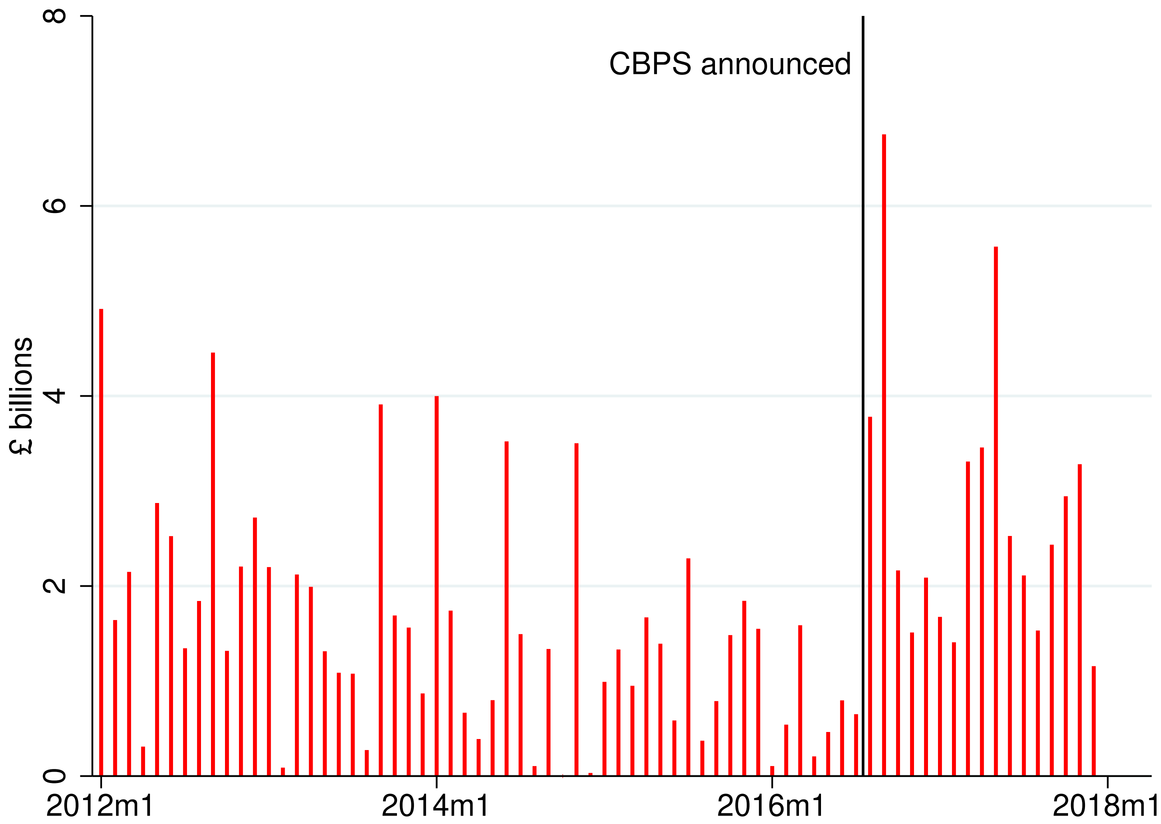
Figure 1: Corporate bond spreads



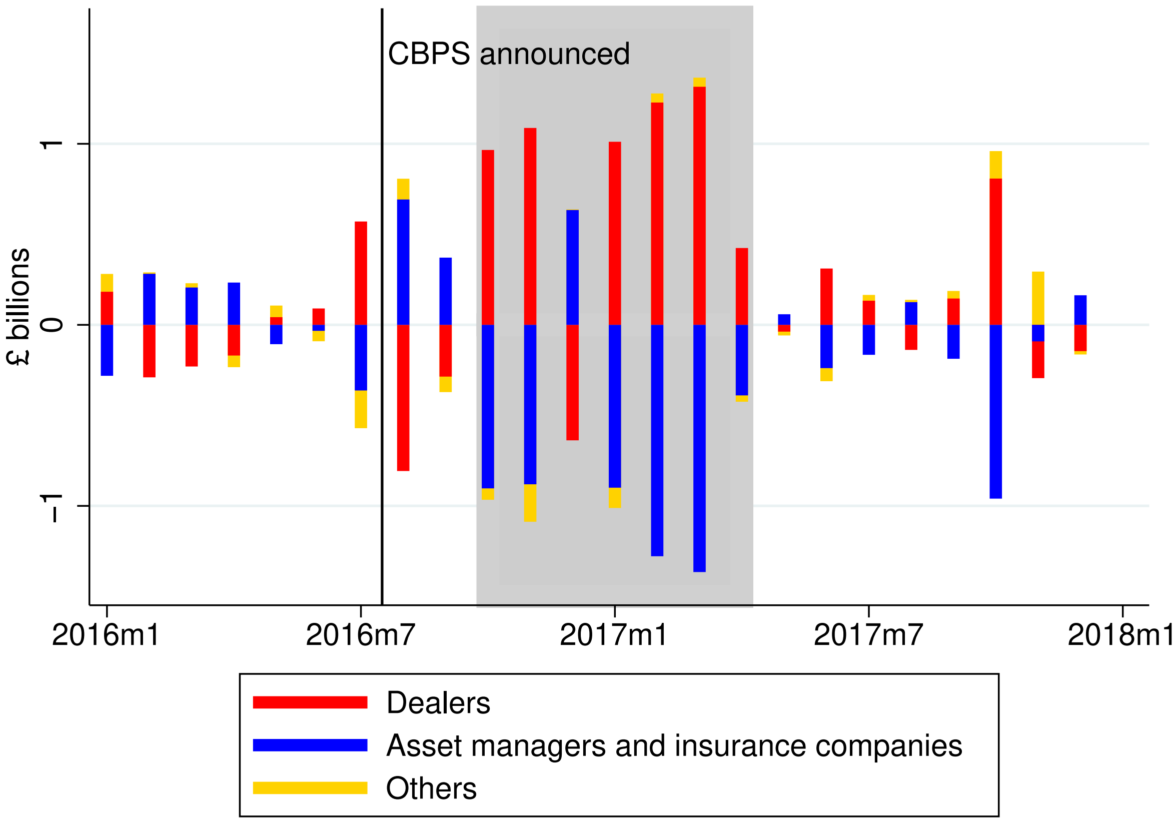
Notes: The chart shows option-adjusted spreads for investment grade non-financial corporate bonds. The shaded region shows the period of CBPS purchases.
Source: Bank of America.

Figure 2: Sterling corporate bond issuance



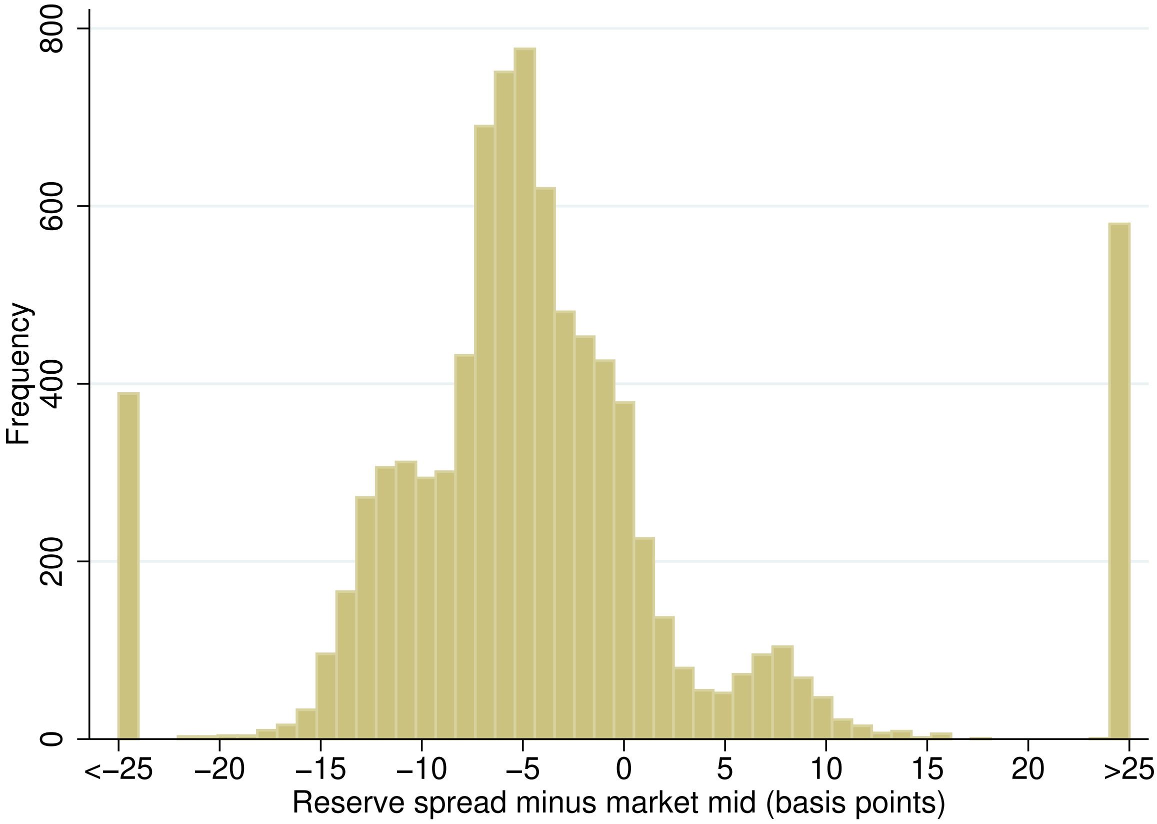
Notes: The chart shows monthly gross issuance of sterling-denominated investment grade non-financial corporate bonds.
Source: Thomson Reuters.

Figure 3: Net trading in eligible corporate bonds



Notes: The chart shows monthly net secondary market trading volumes in bonds that were eligible for the CBPS, estimated using the transaction-level Zen dataset. Primary market trades and trades with the CBPS itself are excluded. Positive numbers indicate net buying volume while negative numbers indicate net selling volume. The shaded region shows the period of CBPS purchases.

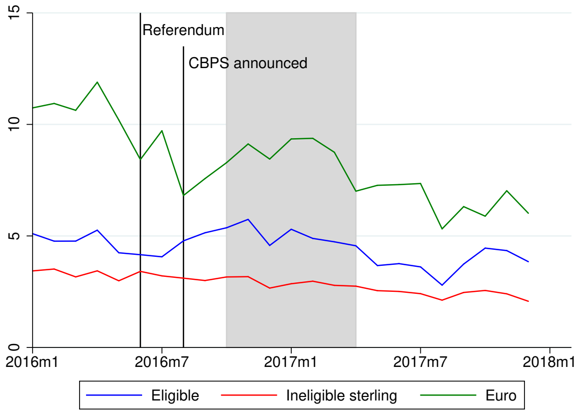
Figure 4: Distribution of reserve spreads



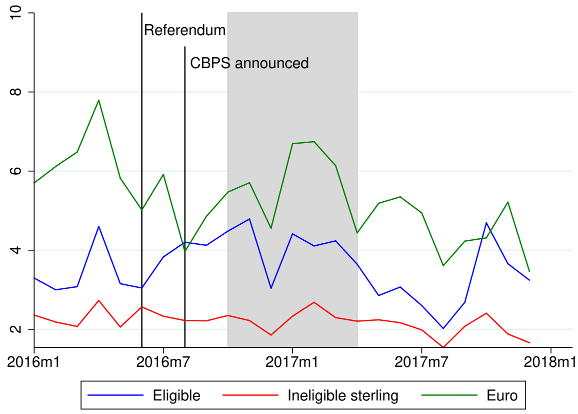
Notes: The chart shows a histogram of the reserve spreads set by the Bank of England ahead of CBPS auctions. Quoted market mid spreads have been subtracted from the reserve spreads. Spreads greater than 25 basis points are allocated to the highest bin, and spreads less than -25 basis points are allocated to the lowest bin.

Figure 5: Measures of trading activity

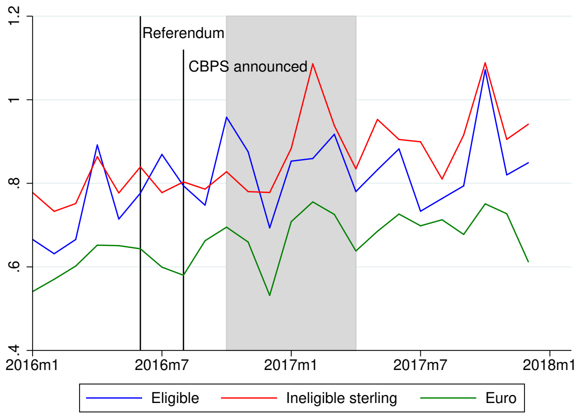
(a) Number of trades per week



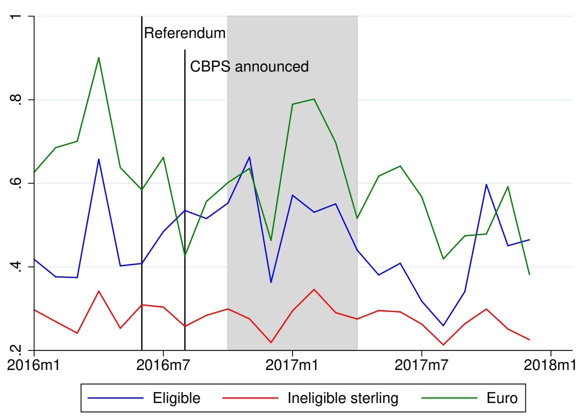
(b) Weekly trading volume (£mn)



(c) Average trade size (£mn)



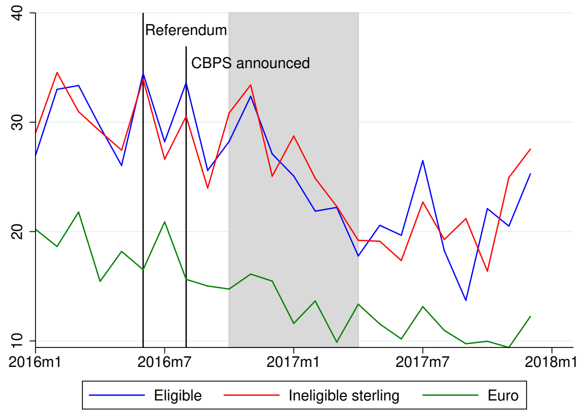
(d) Number of large trades per week



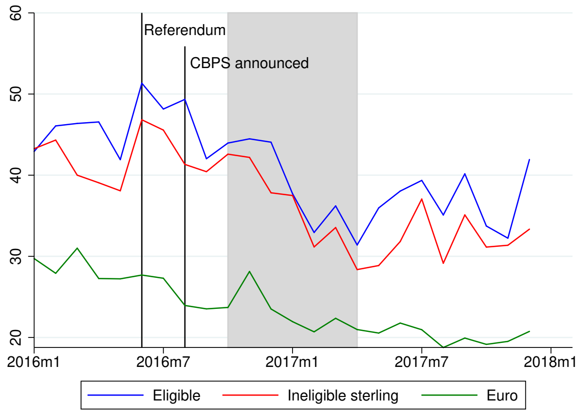
Notes: The charts show liquidity measures for the corporate bond market estimated using the transaction-level Zen dataset. The measures are computed for individual bonds at weekly frequency, then averaged across bonds within a group. The charts show monthly averages. 'Eligible' refers to bonds that were at some point eligible for the CBPS. 'Ineligible sterling' refers to sterling-denominated investment grade corporate bonds that were never eligible for the CBPS (bonds issued by banks and insurance companies are excluded). 'Euro' refers to euro-denominated bonds issued by issuers who had also issued eligible bonds. The shaded region shows the period of CBPS purchases. Higher numbers indicate better liquidity. Definitions of the measures are provided in Appendix A.

Figure 6: Measures of transaction costs and price impact

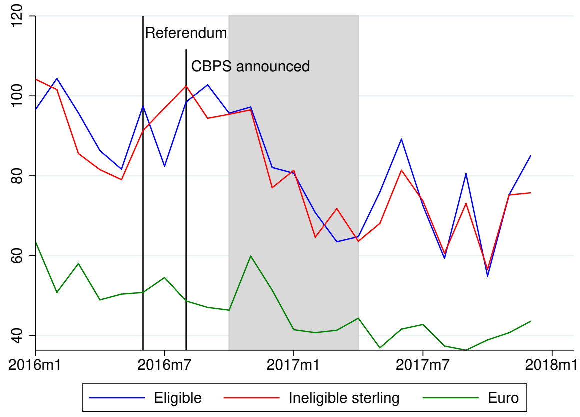
(a) Effective spread (bps)



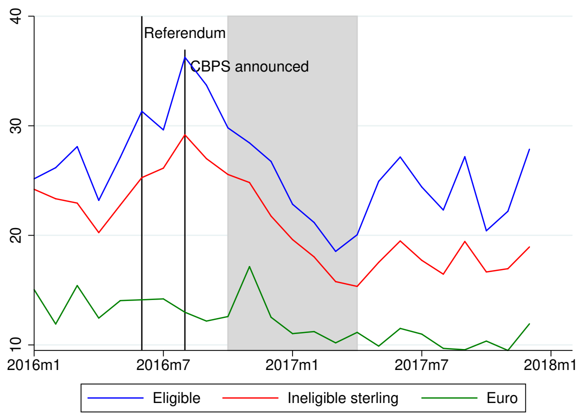
(b) Roll (bps)



(c) Amihud (bps)



(d) Volatility-over-volume (bps)



Notes: The charts show liquidity measures for the corporate bond market estimated using the transaction-level Zen dataset. The measures are computed for individual bonds at weekly frequency, then averaged across bonds within a group. The charts show monthly averages. 'Eligible' refers to bonds that were at some point eligible for the CBPS. 'Ineligible sterling' refers to sterling-denominated investment grade corporate bonds that were never eligible for the CBPS (bonds issued by banks and insurance companies are excluded). 'Euro' refers to euro-denominated bonds issued by issuers who had also issued eligible bonds. The shaded region shows the period of CBPS purchases. Higher numbers indicate worse liquidity. Definitions of the measures are provided in Appendix A.

Table 1: Summary statistics: Auction variables

Statistic:	N	Mean	Std dev	Min	Median	Max
Total amount offered (GBP mn)	4,275	9.16	9.03	1.0	6.3	78.6
Average offer spread (bps)	4,275	1.25	4.63	-62.0	1.6	25.0
Total amount purchased (GBP mn)	1,622	4.83	3.29	0.1	4.0	10.0

Notes: The table shows summary statistics from the offer-level CBPS auction dataset. One observation refers to a bond-auction pair. 'Total amount offered' is the total quantity of a single bond offered by auction participants in a single auction, in nominal terms. 'Average offer spread' is the volume-weighted average spread between auction participants' offer yields and the average offer yield quoted in the secondary market. 'Total amount purchased' is the total quantity of a single bond purchased in a single auction, in nominal terms. The summary statistics for total amount offered and average offer spread are computed using observations where there was at least one offer for the bond in the auction. The summary statistics for total amount purchased are computed using observations where the bond was purchased in the auction.

Table 2: Summary statistics: Liquidity measures

Statistic:	N	Mean	Std dev	Min	Median	Max
Eligible bonds						
COUNT	36,042	4.42	6.12	0.00	3.00	196.00
VOLUME (GBP mn)	36,042	3.53	7.19	0.00	0.94	274.40
SIZE (GBP mn)	27,383	0.81	1.11	0.00	0.48	27.64
LARGE	36,042	0.45	1.11	0.00	0.00	24.00
SPREAD (bps)	14,724	25.83	42.77	-61.82	18.13	140.53
ROLL (bps)	14,781	40.90	47.26	0.00	25.15	186.73
AMIHUD (bps)	20,063	83.29	103.90	0.00	44.08	442.22
VOV (bps)	14,781	25.95	30.05	0.94	15.04	132.73
Ineligible sterling investment grade bonds						
COUNT	52,166	2.81	6.88	0.00	0.00	156.00
VOLUME (GBP mn)	52,166	2.16	6.35	0.00	0.00	158.30
SIZE (GBP mn)	20,161	0.86	1.36	0.00	0.50	29.97
LARGE	52,166	0.27	0.94	0.00	0.00	27.00
SPREAD (bps)	11,437	25.82	41.11	-61.82	18.48	140.53
ROLL (bps)	11,614	37.45	42.49	0.00	24.14	186.73
AMIHUD (bps)	15,459	81.76	101.04	0.00	44.26	442.22
VOV (bps)	11,614	21.19	25.90	0.94	12.18	132.73
Euro-denominated bonds issued by eligible issuers						
COUNT	56,659	8.15	14.42	0.00	4.00	610.00
VOLUME (GBP mn)	56,659	5.23	11.14	0.00	1.31	322.89
SIZE (GBP mn)	39,896	0.66	0.89	0.00	0.44	27.04
LARGE	56,659	0.59	1.54	0.00	0.00	53.00
SPREAD (bps)	25,432	14.32	29.15	-61.82	9.98	140.53
ROLL (bps)	29,930	23.70	28.69	0.00	14.90	186.73
AMIHUD (bps)	32,176	46.32	61.80	0.00	26.64	442.22
VOV (bps)	29,930	12.15	17.33	0.94	6.96	132.73

Notes: The table shows summary statistics for corporate bond liquidity measures estimated using the transaction-level Zen dataset. The measures are computed at the bond level and at weekly frequency. The sample period is January 2016 to December 2017. Definitions of the measures are provided in Appendix A. SPREAD, ROLL, AMIHUD and VOV are winsorised at 2.5% and 97.5%.

Table 3: Announcement effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Sterling control group								
Eligible	0.185	0.711	-0.064	0.095	5.106	2.618	-16.562	-2.657
	(0.831)	(0.932)	(0.170)	(0.142)	(10.069)	(9.619)	(21.919)	(5.701)
Observations	545	545	316	545	136	154	226	154
R^2	0.085	0.107	0.028	0.084	0.079	0.114	0.058	0.093
Panel B: Euro control group								
Eligible	3.026*	4.530***	0.240*	0.451**	22.446***	-7.351	-14.164	-6.172*
	(1.547)	(1.568)	(0.128)	(0.217)	(7.277)	(6.528)	(13.290)	(3.343)
Observations	690	690	505	690	213	287	355	287
R^2	0.153	0.098	0.016	0.092	0.099	0.039	0.081	0.056

Notes: The table shows regression results for equation (1). The regressions are estimated at the bond level. The dependent variable is the change in liquidity from the week before the CBPS was announced (25 – 29 July 2016) to the week after the CBPS was announced (8 – 12 August 2016). Different columns correspond to different liquidity measures. 'Eligible' is an indicator variable equal to one for bonds that were eligible for purchase by the CBPS, and zero otherwise. All regressions include the following bond-level controls (measured before the announcement): amount outstanding, credit rating, residual maturity, residual maturity squared, industry fixed effects, yield spread to the reference government bond, and amount outstanding of gilts with a similar residual maturity (within two years). Control groups are defined in Section 4. Standard errors are robust to heteroskedasticity and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 4: Impact of CBPS purchases on liquidity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	0.289***	0.739***	0.114***	0.091***	-0.854**	-0.357*	-0.828*	-0.684***
	(0.045)	(0.057)	(0.013)	(0.009)	(0.347)	(0.180)	(0.462)	(0.114)
Observations	4266	4266	3915	4266	2539	2620	3320	2620
R^2	0.431	0.309	0.280	0.237	0.206	0.323	0.280	0.490
Panel B: Limit control group								
Amount purchased	0.246***	0.776***	0.142***	0.090***	-0.850*	-0.693**	-2.080***	-0.877***
	(0.059)	(0.068)	(0.017)	(0.010)	(0.428)	(0.306)	(0.566)	(0.135)
Observations	2579	2579	2399	2579	1575	1611	2052	1611
R^2	0.441	0.368	0.366	0.286	0.258	0.342	0.321	0.543
Panel C: Sterling control group								
Amount purchased	0.385***	0.978***	0.145***	0.108***	-0.950*	-0.537	-2.742***	-0.941***
	(0.064)	(0.066)	(0.020)	(0.009)	(0.512)	(0.368)	(0.704)	(0.128)
Observations	14594	14594	6546	14594	3880	3932	5221	3932
R^2	0.623	0.394	0.325	0.319	0.224	0.291	0.280	0.560
Panel D: Euro control group								
Amount purchased	0.389***	0.978***	0.144***	0.110***	-0.887*	-0.407	-2.301***	-0.847***
	(0.062)	(0.065)	(0.020)	(0.009)	(0.491)	(0.371)	(0.692)	(0.150)
Observations	16540	16540	12240	16540	7824	9190	10096	9190
R^2	0.604	0.468	0.291	0.397	0.203	0.275	0.293	0.506

Notes: The table shows regression results for equation (3). The regressions are estimated at the bond-auction level. The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The regressions using the Offer and Limit control groups include proxy variables for the BoE's demand and auction participants' supply (defined in Section 5.2). The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 5: Impact of CBPS purchases on liquidity – controlling for lagged liquidity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	0.257***	0.716***	0.085***	0.084***	-0.882	-0.503	-1.158	-0.617***
	(0.050)	(0.071)	(0.013)	(0.011)	(0.595)	(0.428)	(0.801)	(0.219)
Lagged liquidity	0.004	0.117***	0.006	0.084***	0.052	0.027	-0.047	0.062
	(0.063)	(0.033)	(0.038)	(0.028)	(0.058)	(0.047)	(0.035)	(0.064)
Observations	3933	3933	3364	3933	1605	1808	2554	1808
Panel B: Limit control group								
Amount purchased	0.215***	0.697***	0.094***	0.086***	-1.422*	-0.330	-1.857**	-0.764***
	(0.060)	(0.082)	(0.015)	(0.013)	(0.739)	(0.549)	(0.937)	(0.278)
Lagged liquidity	-0.022	0.130***	-0.035	0.083**	-0.024	-0.021	-0.084**	0.009
	(0.083)	(0.046)	(0.046)	(0.034)	(0.077)	(0.064)	(0.043)	(0.067)
Observations	2395	2395	2073	2395	1011	1131	1587	1131
Panel C: Sterling control group								
Amount purchased	0.264***	0.600***	0.067***	0.073***	-1.135**	-0.923*	-2.515***	-0.969***
	(0.058)	(0.074)	(0.013)	(0.012)	(0.567)	(0.496)	(0.934)	(0.252)
Lagged liquidity	0.113***	0.102***	0.007	0.062***	-0.026	0.079*	0.020	0.076**
	(0.028)	(0.023)	(0.034)	(0.021)	(0.056)	(0.041)	(0.033)	(0.038)
Observations	13559	13559	5324	13559	2347	2641	3787	2641
Panel D: Euro control group								
Amount purchased	0.274***	0.614***	0.069***	0.074***	-1.162**	-0.778*	-2.177**	-0.774***
	(0.060)	(0.074)	(0.013)	(0.012)	(0.542)	(0.445)	(0.853)	(0.243)
Lagged liquidity	0.126***	0.122***	-0.000	0.067***	-0.022	-0.003	-0.009	0.069*
	(0.034)	(0.024)	(0.024)	(0.020)	(0.031)	(0.035)	(0.026)	(0.040)
Observations	15327	15327	10734	15327	5247	7019	7982	7019

Notes: The table shows regression results for equation (3). The regressions are estimated at the bond-auction level using the system GMM estimator of Blundell and Bond (1998). The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The regressions using the Offer and Limit control groups include proxy variables for the BoE's demand and auction participants' supply (defined in Section 5.2). The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 6: Impact of CBPS purchases on liquidity – instrumental variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Eligible control group								
Amount purchased	0.616***	1.461***	0.257***	0.200***	0.494	-1.592	-4.163**	-2.292***
	(0.140)	(0.168)	(0.035)	(0.028)	(0.911)	(0.968)	(1.816)	(0.480)
Observations	8381	8381	6627	8381	3746	3731	5088	3731
First-stage F-statistic	135.986	135.986	148.161	135.986	134.887	106.506	114.844	106.506
Panel B: Offer control group								
Amount purchased	0.436**	1.224***	0.212***	0.156***	-0.967	-2.048**	-5.369**	-1.640***
	(0.171)	(0.189)	(0.036)	(0.032)	(1.011)	(0.900)	(2.108)	(0.442)
Observations	3927	3927	3621	3927	2358	2433	3082	2433
First-stage F-statistic	110.245	110.245	106.572	110.245	75.430	86.800	80.827	86.800
Panel C: Limit control group								
Amount purchased	0.378**	1.083***	0.178***	0.126***	-1.773	-1.344	-5.245**	-0.909*
	(0.163)	(0.215)	(0.041)	(0.036)	(1.241)	(0.992)	(2.527)	(0.466)
Observations	2322	2322	2169	2322	1427	1453	1862	1453
First-stage F-statistic	97.214	97.214	94.797	97.214	64.031	75.709	71.937	75.709

Notes: The table shows regression results for equation (4). The regressions are estimated at the bond-auction level. The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. This variable is instrumented using the proportion of the bond-level purchase limit still available for purchase. All regressions include bond and auction fixed effects. Control groups are defined in Section 5.3. The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 7: Impact of CBPS purchases on liquidity – heterogeneity by pre-CBPS liquidity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	0.299***	0.772***	0.120***	0.094***	-1.274***	-0.515*	-0.376	-0.796***
	(0.042)	(0.059)	(0.015)	(0.009)	(0.464)	(0.275)	(0.486)	(0.150)
Amount purchased	-0.004	0.000	0.012	-0.001	-0.019*	0.004	-0.004	-0.004
× Pre-CBPS liquidity	(0.005)	(0.008)	(0.013)	(0.010)	(0.010)	(0.009)	(0.006)	(0.006)
Observations	3939	3939	3148	3939	1337	1523	2279	1523
R^2	0.368	0.298	0.271	0.230	0.216	0.354	0.292	0.510
Panel B: Limit control group								
Amount purchased	0.257***	0.797***	0.137***	0.091***	-0.796	-0.900**	-2.062***	-1.038***
	(0.056)	(0.072)	(0.018)	(0.011)	(0.547)	(0.430)	(0.714)	(0.200)
Amount purchased	-0.005	-0.001	0.016	-0.003	-0.009	0.008	-0.002	-0.005
× Pre-CBPS liquidity	(0.007)	(0.007)	(0.014)	(0.009)	(0.010)	(0.011)	(0.009)	(0.007)
Observations	2406	2406	1939	2406	834	932	1404	932
R^2	0.384	0.355	0.363	0.271	0.304	0.367	0.345	0.580
Panel C: Sterling control group								
Amount purchased	0.335***	0.965***	0.144***	0.104***	-1.532***	-0.510	-3.143***	-0.780***
	(0.068)	(0.078)	(0.021)	(0.010)	(0.575)	(0.470)	(0.842)	(0.149)
Amount purchased	0.006	0.002	-0.004	0.004	-0.016	-0.001	-0.014	-0.009
× Pre-CBPS liquidity	(0.008)	(0.005)	(0.014)	(0.005)	(0.012)	(0.012)	(0.011)	(0.009)
Observations	13929	13929	5004	13929	2153	2369	3520	2369
R^2	0.618	0.384	0.329	0.312	0.207	0.308	0.275	0.602
Panel D: Euro control group								
Amount purchased	0.384***	0.980***	0.145***	0.108***	-1.102*	-0.423	-1.930**	-0.529***
	(0.076)	(0.066)	(0.021)	(0.009)	(0.574)	(0.517)	(0.755)	(0.120)
Amount purchased	0.005	0.001	-0.006	0.003	-0.017	0.002	-0.017	-0.012
× Pre-CBPS liquidity	(0.008)	(0.005)	(0.014)	(0.005)	(0.012)	(0.012)	(0.012)	(0.010)
Observations	15310	15310	10771	15310	5112	6950	7861	6950
R^2	0.606	0.417	0.277	0.322	0.210	0.280	0.292	0.519

Notes: The table shows regression results for equation (5). The regressions are estimated at the bond-auction level. The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. 'Pre-CBPS liquidity' is the level of liquidity for the bond in the week before the announcement of the CBPS (demeaned across bonds). All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The regressions using the Offer and Limit control groups include proxy variables for the BoE's demand and auction participants' supply (defined in Section 5.2), both in levels and interacted with 'Pre-CBPS liquidity.' The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 8: Impact of CBPS purchases on liquidity – variation over time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	0.266***	0.682***	0.103***	0.085***	-0.556	-0.332	-0.776	-0.569***
	(0.043)	(0.063)	(0.012)	(0.010)	(0.335)	(0.200)	(0.508)	(0.114)
Amount purchased × Trend	-0.009*	-0.022***	-0.004***	-0.002**	0.048	-0.005	0.029	0.029**
	(0.005)	(0.007)	(0.001)	(0.001)	(0.037)	(0.023)	(0.059)	(0.014)
Observations	4266	4266	3915	4266	2539	2620	3320	2620
R^2	0.433	0.313	0.287	0.239	0.211	0.324	0.280	0.492
Panel B: Limit control group								
Amount purchased	0.229***	0.694***	0.130***	0.080***	-0.573	-1.248***	-2.171***	-0.771***
	(0.055)	(0.071)	(0.016)	(0.011)	(0.448)	(0.351)	(0.567)	(0.142)
Amount purchased × Trend	-0.006	-0.021***	-0.003*	-0.003**	0.056	-0.082**	-0.034	0.011
	(0.006)	(0.008)	(0.002)	(0.001)	(0.053)	(0.039)	(0.069)	(0.015)
Observations	2579	2579	2399	2579	1575	1611	2052	1611
R^2	0.442	0.371	0.372	0.288	0.261	0.348	0.321	0.545
Panel C: Sterling control group								
Amount purchased	0.342***	0.899***	0.128***	0.098***	-0.757	-0.528	-2.488***	-0.889***
	(0.053)	(0.064)	(0.019)	(0.009)	(0.473)	(0.359)	(0.722)	(0.122)
Amount purchased × Trend	-0.010*	-0.018***	-0.004***	-0.002***	0.041	0.002	0.057	0.012
	(0.005)	(0.005)	(0.001)	(0.001)	(0.042)	(0.025)	(0.058)	(0.010)
Observations	14594	14594	6546	14594	3880	3932	5221	3932
R^2	0.623	0.396	0.327	0.320	0.225	0.291	0.280	0.560
Panel D: Euro control group								
Amount purchased	0.347***	0.899***	0.128***	0.099***	-0.867*	-0.607	-2.760***	-0.983***
	(0.054)	(0.064)	(0.019)	(0.009)	(0.467)	(0.366)	(0.717)	(0.157)
Amount purchased × Trend	-0.009	-0.017***	-0.003***	-0.002***	0.004	-0.044**	-0.099*	-0.030**
	(0.006)	(0.006)	(0.001)	(0.001)	(0.037)	(0.021)	(0.057)	(0.014)
Observations	16540	16540	12240	16540	7824	9190	10096	9190
R^2	0.604	0.469	0.294	0.397	0.203	0.275	0.294	0.506

Notes: The table shows regression results for equation (6). The regressions are estimated at the bond-auction level. The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. 'Trend' is a linear time trend at weekly frequency (defined to be zero at the midpoint of the purchase period). All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The regressions using the Offer and Limit control groups include proxy variables for the BoE's demand and auction participants' supply (defined in Section 5.2), both in levels and interacted with 'Trend.' The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 9: Stock effects of CBPS on liquidity

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Eligible control group								
Amount purchased	0.006	-0.038	0.001	-0.005	0.228	0.119	-0.572	-0.042
	(0.035)	(0.034)	(0.011)	(0.005)	(0.474)	(0.495)	(0.632)	(0.256)
Observations	311	311	183	311	41	56	94	56
R^2	0.091	0.063	0.122	0.078	0.537	0.311	0.254	0.195
Panel B: Sterling control group								
Amount purchased	-0.005	-0.067**	-0.002	-0.009**	0.369	0.092	-0.873*	0.035
	(0.022)	(0.026)	(0.007)	(0.004)	(0.325)	(0.257)	(0.477)	(0.157)
Observations	493	493	279	493	83	88	158	88
R^2	0.092	0.074	0.095	0.082	0.239	0.214	0.136	0.144

Notes: The table shows regression results for equation (7). The regressions are estimated at the bond level. The dependent variable is the change in liquidity from the week before the CBPS was announced (25 – 29 July 2016) to the week after purchases were completed (1 – 5 May 2017). Different columns correspond to different liquidity measures. 'Amount purchased' is the total quantity of the bond purchased by the CBPS over the entire purchase period, denominated in sterling millions. All regressions include the following bond-level controls measured before the announcement: amount outstanding, credit rating, residual maturity, residual maturity squared, industry fixed effects, yield spread to the reference gilt, and amount outstanding of gilts with a similar residual maturity (within two years). The regressions also include the following bond-level controls computed over the duration of the scheme: change in credit rating, change in amount outstanding of gilts with a similar residual maturity, and BoE QE purchases of gilts with a similar maturity. Control groups are defined in Section 6. Standard errors are robust to heteroskedasticity and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

A Definitions of liquidity measures

We compute eight liquidity measures using the transaction-level Zen dataset. All measures are computed at the level of individual bonds, and at weekly frequency.

COUNT Number of trades within the week.

VOLUME Total trading volume within the week, denominated in £mn.

SIZE Average trade size, denominated in £mn.

LARGE Number of trades with a market value greater than or equal to £2mn, which is approximately the 90th percentile of the trade size distribution.

SPREAD The effective spread is used by Hong and Warga (2000), among others, as an estimate of the average bid-ask spread. We compute this measure as the volume-weighted average price in trades where a dealer is selling to a non-dealer, minus the volume-weighted average price in trades where a dealer is buying from a non-dealer, divided by the volume-weighted average price across all trades. The units are basis points. To compute this measure, we require there to be at least one sell trade and one buy trade within the week.

ROLL Roll (1984) shows that under certain assumptions, the effective bid-ask spread is equal to two times the square root of the negative of the first-order serial covariance of returns. For a given bond and a given week, define r_i to be the return on the ith trade. We then compute the Roll measure as

$$ROLL = 2\sqrt{\max\left\{0, -\text{cov}\left(r_i, r_{i-1}\right)\right\}}.$$

The units are basis points. We only compute this measure for weeks with at least four trades.

AMIHUD Amihud (2002) measures liquidity as the ratio of absolute return to trading volume. This measure is intended to capture the price impact of trading. Following Dick-Nielsen et al. (2012), we compute the Amihud measure at the level of individual trades, then average over the trade-level values each week to obtain a measure at weekly frequency. More precisely, for a given bond and a given week, define r_i to be the return and Q_i to be the trade size (in £mn) of the ith trade, and define N to be the number of trades. We then compute the Amihud measure as

$$AMIHUD = \frac{1}{N-1} \sum_{i=2}^{N} \frac{|r_i|}{Q_i}.$$

The units are basis points. We require at least two trades within the week to compute this measure. We exclude trades smaller than £100k since these can introduce significant noise.

VOV As an additional measure of price impact, we use the volatility-over-volume measure of Fong et al. (2017). For a given bond and a given week, let σ^2 be the variance of traded prices and let V be the total trading volume (in £mn). We then compute volatility-over-volume as

$$VOV = \sqrt{\frac{\sigma^2}{V}}.$$

The units are basis points, and we only compute this measure for weeks with at least four trades.

B Econometric model

We provide an econometric justification for the model in Section 5.2. We suppose that liquidity is determined by the following equation:

$$L_{bt} = \alpha_b + \mu_t + \beta P_{bt} + \delta^\intercal Z_{bt} + e_{bt}, \tag{8}$$

where L_{bt} denotes the liquidity of bond b in period t, P_{bt} denotes auction purchases, and $Z_{bt} \in \mathbb{R}^{k_z}$ is a vector of latent signals about liquidity observed by market participants but not by the econometrician. We suppose that purchases are determined by demand and supply factors, so that

$$P_{bt} = a_b + c_t + \theta^\intercal X_{bt} + u_{bt}, \tag{9}$$

where $X_{bt} = (D_{bt}^\intercal, S_{bt}^\intercal)^\intercal \in \mathbb{R}^{k_x}$. The demand and supply factors are themselves driven by the latent liquidity factor, i.e.,

$$X_{bt} = \omega_b + \phi_t + BZ_{bt} + v_{bt}. \tag{10}$$

Here, α_b, μ_t, a_b, c_t, ω_b, and ϕ_t are unobserved bond-specific and time-specific fixed effects whose relations with other variables are not restricted in any way. Because Z_{bt} is not observed, the usual difference-in-differences estimator of liquidity L_{bt} on purchases P_{bt} would be inconsistent. The model shares some similarities with Pesaran (2006), except that the latent factors in our case vary over both bonds and time in an unspecified way.

Suppose that $k_x = k_z = k$ and that B is of full rank.[14] In this case, we may write

$$Z_{bt} = B^{-1}\left(X_{bt} - v_{bt} - \omega_b - \phi_t\right),$$

and hence substituting into (8) we obtain

$$L_{bt} = \alpha_b^* + \gamma_t^* + \beta P_{bt} + d^\intercal X_{bt} + e_{bt}^*, \tag{11}$$

where $e_{bt}^* = e_{bt} - \delta^\intercal B^{-1} v_{bt}$ is a linear combination of e_{bt} and v_{bt}, while α_b^* and γ_t^* are linear combinations of the fixed effects from the liquidity equation, the demand equation, and

[14] This is only for exposition; the argument also works provided $\mathrm{rank}(B) \geq k_z$, i.e., more X than Z.

the supply equation. Taking double differences (across b and t), we obtain

$$\begin{aligned} \widetilde{L}_{bt} &= \beta \widetilde{P}_{bt} + d^{\intercal} \widetilde{X}_{bt} + \widetilde{e}^{*}_{bt} \\ \widetilde{P}_{bt} &= \theta^{\intercal} \widetilde{X}_{bt} + \widetilde{u}_{bt} \\ \widetilde{X}_{bt} &= B \widetilde{Z}_{bt} + \widetilde{v}_{bt}, \end{aligned} \tag{12}$$

where $\widetilde{L}_{bt} = \Delta\Delta L_{bt}$, $\widetilde{P}_{bt} = \Delta\Delta P_{bt}$, etc. Note that $\widetilde{e}^{*}_{bt}$ contains $\widetilde{v}_{bt}$, which is correlated with $\widetilde{X}_{bt}$ and $\widetilde{P}_{bt}$, the included variables in (12), the equation of interest. This is like the classical measurement error problem: since X is an imperfect measure of Z, it usually leads to biased OLS coefficients (Aigner et al., 1984). However, because P is only driven by L through Z, this effect can be eliminated, at least as far as the main effect of interest, using the partitioned regression formula. Let $E_L(Y|X)$ denote the best linear predictor of a random variable Y by a random variable X. We have

$$E_L(\widetilde{L}_{bt}|\widetilde{X}_{bt}) = \beta E_L(\widetilde{P}_{bt}|\widetilde{X}_{bt}) + d^{\intercal} \widetilde{X}_{bt} + E_L(\widetilde{e}^{*}_{bt}|\widetilde{X}_{bt}),$$

using the linearity of the operator $E_L(\cdot|\cdot)$. Subtracting from (12) we obtain

$$\widetilde{L}_{bt} - E_L(\widetilde{L}_{bt}|\widetilde{X}_{bt}) = \beta \left(\widetilde{P}_{bt} - E_L(\widetilde{P}_{bt}|\widetilde{X}_{bt}) \right) + \left(\widetilde{e}^{*}_{bt} - E_L(\widetilde{e}^{*}_{bt}|\widetilde{X}_{bt}) \right).$$

Now, since $\widetilde{P}_{bt} - E_L(\widetilde{P}_{bt}|\widetilde{X}_{bt}) = \widetilde{u}_{bt}$, provided $E_L(\widetilde{e}_{bt}, \widetilde{v}_{bt}, \widetilde{X}_{bt}|\widetilde{u}_{bt}) = 0$, the slope of the best linear predictor of $\widetilde{L}_{bt} - E_L(\widetilde{L}_{bt}|\widetilde{X}_{bt})$ by $(\widetilde{P}_{bt} - E_L(\widetilde{P}_{bt}|\widetilde{X}_{bt}))$ is β. Therefore, for identification of β it suffices that the following unconditional moment conditions are satisfied:

$$E\left(\widetilde{e}_{bt} \times \widetilde{u}_{bt}\right) = 0 \tag{13}$$

$$E\left(\widetilde{v}_{bt} \times \widetilde{u}_{bt}\right) = 0 \tag{14}$$

$$E\left(Z_{bt} \times \widetilde{u}_{bt}\right) = 0. \tag{15}$$

In practice, we construct the OLS estimator of β from (12) by the partitioned regression formula

$$\widehat{\beta} = \left(\mathcal{P}^{\intercal} \mathcal{M}_x \mathcal{P}\right)^{-1} \mathcal{P}^{\intercal} \mathcal{M}_x \mathcal{L} = \beta + \left(\mathcal{P}^{\intercal} \mathcal{M}_x \mathcal{P}\right)^{-1} \mathcal{P}^{\intercal} \mathcal{M}_x \mathcal{E}^{*},$$

where $\mathcal{P}$ is the $nT \times 1$ vector containing the observations $\widetilde{P}_{bt}$, $\mathcal{L}$ is the $nT \times 1$ vector containing the observations $\widetilde{L}_{bt}$, while

$$\mathcal{M}_x = I_{nT} - \mathcal{X}(\mathcal{X}^\intercal \mathcal{X})^{-1} \mathcal{X}^\intercal,$$

where $\mathcal{X}$ is the $nT \times k$ matrix containing the observations $\widetilde{X}_{bt}$. Here, $\mathcal{E}^*$ is the $nT \times 1$ vector containing the observations $\widetilde{e}^*_{bt}$. The partialling out by $\mathcal{M}_x$ removes the source of correlation between the error term in (12) and the included variables.

The moment conditions (13) - (15), along with technical conditions (that are standard in the difference-in-differences literature) to ensure laws of large numbers and central limit theorems, guarantee the large sample approximations we use in the paper. The estimates of d are not particularly meaningful as they involve a number of underlying parameters (these estimates will be affected by the measurement error bias anyway).

C Robustness tests

Table 10: Impact of CBPS purchases on liquidity – without supply and demand controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	0.313***	0.758***	0.118***	0.096***	-0.743**	-0.358**	-0.980***	-0.679***
	(0.044)	(0.052)	(0.013)	(0.007)	(0.316)	(0.165)	(0.371)	(0.091)
Observations	4266	4266	3915	4266	2539	2620	3320	2620
R^2	0.430	0.306	0.278	0.235	0.206	0.322	0.279	0.490
Panel B: Limit control group								
Amount purchased	0.345***	0.829***	0.130***	0.102***	-0.916**	-0.349	-1.785***	-0.693***
	(0.052)	(0.055)	(0.016)	(0.008)	(0.373)	(0.242)	(0.526)	(0.105)
Observations	2579	2579	2399	2579	1575	1611	2052	1611
R^2	0.438	0.364	0.363	0.283	0.256	0.341	0.320	0.540

Notes: The table shows regression results for equation (3), excluding the proxy variables for supply and demand. The regressions are estimated at the bond-auction level. The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 11: Impact of CBPS purchases on liquidity – scaled purchases

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	92.3***	250.3***	49.4***	30.1***	-369.9***	-178.2*	-358.1**	-317.1***
	(17.0)	(22.8)	(6.1)	(3.3)	(134.2)	(97.6)	(166.1)	(45.9)
Observations	4266	4266	3915	4266	2539	2620	3320	2620
R^2	0.429	0.300	0.293	0.230	0.206	0.323	0.280	0.491
Panel B: Limit control group								
Amount purchased	66.3***	235.5***	57.5***	26.3***	-272.5	-263.7*	-776.6***	-342.3***
	(21.2)	(25.3)	(7.4)	(3.5)	(179.3)	(138.3)	(223.7)	(56.2)
Observations	2579	2579	2399	2579	1575	1611	2052	1611
R^2	0.438	0.355	0.376	0.278	0.257	0.342	0.321	0.542
Panel C: Sterling control group								
Amount purchased	119.3***	334.4***	59.6***	36.7***	-358.3	-307.4*	-1232.1***	-446.8***
	(20.0)	(27.4)	(8.8)	(3.5)	(217.7)	(169.7)	(288.1)	(72.2)
Observations	14594	14594	6546	14594	3880	3932	5221	3932
R^2	0.622	0.391	0.327	0.317	0.224	0.291	0.281	0.560
Panel D: Euro control group								
Amount purchased	120.2***	334.1***	58.9***	37.1***	-320.8	-244.1	-1088.8***	-396.4***
	(19.8)	(27.0)	(8.8)	(3.5)	(209.7)	(176.1)	(284.3)	(79.5)
Observations	16540	16540	12240	16540	7824	9190	10096	9190
R^2	0.604	0.467	0.293	0.396	0.203	0.275	0.294	0.506

Notes: The table shows regression results for equation (3). The regressions are estimated at the bond-auction level. The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, divided by the nominal amount of the bond outstanding. All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The regressions using the Offer and Limit control groups include proxy variables for the BoE's demand and auction participants' supply (defined in Section 5.2). The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

Table 12: Impact of CBPS purchases on liquidity – common correlated effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Liquidity measure:	COUNT	VOLUME	SIZE	LARGE	SPREAD	ROLL	AMIHUD	VOV
Panel A: Offer control group								
Amount purchased	0.291***	0.724***	0.094***	0.083***	-0.924**	-0.518	-1.009	-0.576***
	(0.044)	(0.061)	(0.009)	(0.010)	(0.410)	(0.358)	(0.684)	(0.163)
Observations	4275	4275	3929	4275	2533	2584	3333	2584
Panel B: Limit control group								
Amount purchased	0.310***	0.880***	0.102***	0.101***	-0.537	-1.124*	-2.672**	-0.672***
	(0.080)	(0.104)	(0.016)	(0.017)	(0.724)	(0.618)	(1.181)	(0.258)
Observations	2601	2601	2425	2601	1588	1611	2076	1611
Panel C: Sterling control group								
Amount purchased	0.455***	0.964***	0.140***	0.097***	-0.495	-0.268	-2.141**	-0.559**
	(0.042)	(0.057)	(0.013)	(0.009)	(0.520)	(0.504)	(1.018)	(0.228)
Observations	14596	14596	6526	14596	3742	3836	5140	3836
Panel D: Euro control group								
Amount purchased	0.387***	0.934***	0.134***	0.097***	-0.962**	-0.569	-2.238***	-0.598***
	(0.085)	(0.085)	(0.009)	(0.012)	(0.398)	(0.360)	(0.654)	(0.167)
Observations	16534	16534	12229	16534	7765	9137	10052	9137

Notes: The table shows regression results for equation (3). The regressions are estimated at the bond-auction level using the pooled common correlated effects (CCE) estimator of Pesaran (2006). The dependent variable is liquidity in the week starting on the day of the auction. Different columns correspond to different liquidity measures. 'Amount purchased' is the total nominal quantity of the bond purchased in the auction, denominated in sterling millions. All regressions include bond and auction fixed effects. Control groups are defined in Section 5.2. The regressions using the Offer and Limit control groups include proxy variables for the BoE's demand and auction participants' supply (defined in Section 5.2). The sample period is September 2016 to April 2017. Standard errors are double-clustered at the bond and auction levels, and reported in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.