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QE and the gilt market: a disaggregated analysis

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Martin Daines,[1] Michael A S Joyce[2] and Matthew Tong[3]

Abstract

We examine the impact of the first phase of the Bank of England's quantitative easing (QE) programme during March 2009 to January 2010 on the UK government bond (gilt) market, using high-frequency disaggregated data on individual gilts. We find that: QE announcements took varying amounts of time to get incorporated into market prices and had significant effects on the shape of the term structure; the Bank's reverse auctions were initially associated with additional yield reductions on gilts both eligible and ineligible for purchase; and, allowing for fiscal news and the changing macroeconomic outlook, QE appears to have had persistent effects on gilt yields. In general, our results provide evidence of local supply and duration risk effects consistent with imperfect asset substitution, which has implications beyond the financial crisis for how we think about price determination in the gilt market.

Key words: QE, asset purchases, gilt market, auctions.

JEL classification: G12, E43, C23, C31, C33.

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Summary

In response to the deepening financial crisis in Autumn 2008, central banks in advanced economies reduced their policy rates sharply and introduced a range of other more or less unconventional measures designed to ease monetary conditions and to support financial stability.

In the United Kingdom, a key element of these unconventional monetary policy measures has been the programme of asset purchases financed by central bank money, commonly described as quantitative easing (QE). During the first round of QE purchases over the period from March 2009 to January 2010, the Bank of England (through an indemnified Asset Purchase Facility) bought £200 billion of domestic private and public assets, the vast majority of which were medium to long-term UK government bonds (gilts). By the end of January 2010, the Bank's gilt holdings represented nearly 30% of the stock of nominal gilts outside the official sector. Subsequently, between October 2011 and May 2011, the Bank completed a further £125 billion of purchases and, more recently, at its July 2012 meeting, the MPC voted to increase the size of its asset purchase programme by a further £50 billion to a total of £375 billion.

In this paper we analyse the impact on the gilt market of the first round of QE purchases during March 2009 to January 2010, in order to draw out lessons both about the effectiveness of the policy and also to shed light on the nature of the transmission mechanism from purchases onto bond prices/yields - a key link in the transmission of QE to the wider economy. In conditions where markets are functioning efficiently, one might expect economic news to be quickly assimilated into market prices as soon as it becomes available to market participants. But, given the unprecedented nature of the QE policy and market conditions at the beginning of 2009, it seems possible that the effects of QE may have taken longer than normal to get reflected in prices and indeed that the full market adjustment might have been delayed until the asset purchases were actually made. The contribution of this paper relative to earlier work on QE is to look at the effects of both the announcements (news) about QE and the actual purchases through the Bank's reverse auctions using disaggregated high-frequency data.

Our analysis of the high-frequency market reactions to individual announcements on QE suggests that the initial impact from the announcements took time to be fully priced in and that the cumulative initial impact on yields varied significantly across the term structure, with the largest impact up to 120 basis points between the 15 and 20-year maturity. We also find evidence that gilts with maturities close to or in the Bank's purchase range experienced larger relative yield falls (consistent with 'local supply effects') and that yields also fell more for gilts with longer maturities (consistent with 'duration risk effects').

Analysis of the Bank's reverse auctions suggests that ahead of each auction they led to further yield reductions on gilts both eligible and ineligible for purchase that averaged 2.5 basis points and 1.5 basis points respectively. These effects were not always reversed before close of business on the same day, with more persistent effects found to be positively associated with the degree of price dispersion of the accepted offers, an indicator of price uncertainty. These persistent effects may partly reflect learning by market participants. In addition, we find that the

importance of the overall effects of the auctions on gilt yields diminished over time, as both liquidity and market functioning improved and knowledge of the operation of the Bank's purchase programme increased.

Econometric analysis of the time-series behaviour of gilt yields is consistent with the QE effect on gilt yields being quite persistent, once allowance is made for the countervailing effects on yields of fiscal news and improving macroeconomic prospects during 2009. Putting this finding together with our other results suggests that the peak gilt market response to the Bank's QE policy may not have occurred until the auction purchases began and the market learnt about the effects of the policy.

Overall our results suggest that the Bank's QE asset purchases had a significant and persistent impact on gilt yields. Our paper also provides direct evidence of local supply and duration risk effects consistent with imperfect substitution, which has implications beyond the financial crisis for how we think about price determination in the gilt market.

1 Introduction

In response to the deepening financial crisis in Autumn 2008, central banks in the advanced economies reduced their policy rates sharply and introduced a range of other more or less unconventional measures designed to ease monetary conditions and to support financial stability. In the United Kingdom, one key element of the unconventional monetary policy measures introduced by the Bank of England (henceforth the Bank) was the programme of asset purchases financed by central bank money, commonly described as quantitative easing (QE).[1]

The decision to use QE was announced by the Bank's Monetary Policy Committee (MPC) on 5 March 2009, at the same time as the Committee reduced Bank Rate, the UK policy rate, to 0.5%. The adoption of QE reflected the Committee's belief that there remained a significant risk of undershooting the 2% CPI inflation target unless it undertook further stimulatory measures. The objective of the asset purchases was to produce a large monetary expansion that would ultimately boost nominal expenditure on goods and services and thereby help meet the inflation target.

The aim of this paper is to examine the effects on the UK government bond (gilt) market of the Bank's first round of QE purchases during March 2009 to January 2010. Over this period, the Bank of England (through an indemnified subsidiary, the Bank of England Asset Purchase Facility Fund - henceforth the APF[2]) bought £200 billion of domestic private and public assets, the vast majority of which were medium to long-term gilts. The focus of the purchases on gilts partly reflected the scale and speed of the desired monetary injection. The gilt market is large and liquid out to long maturities,[3] and buying gilts enabled the Bank to meet what initially appeared to be an ambitious programme of purchases (Fisher (2010a)). The Bank's QE purchases were nevertheless large relative to the total amount of gilts outstanding. By the end of January 2010 when £200 billion of purchases had been completed (£198 billion of which were gilts), the Bank's gilt holdings represented nearly 30% of the stock of nominal gilts outside the official sector (the so-called 'free float').[4] Subsequently, between October 2011 and May 2011, the Bank completed a further £125 billion of purchases and more recently, at its July 2012 meeting, the MPC voted to increase the size of its asset purchase programme by a further £50 billion to a total of £375 billion. We only consider the effects of the first round of the Bank's asset purchases in what follows.

The contribution of this paper relative to earlier work on the financial market effects of the Bank's QE policy (eg Meier (2009) and Joyce *et al* (2011a)) is to use high-frequency disaggregated data to analyse the effects on the gilt market of both the related QE policy announcements (containing news about the magnitude of the purchases) and the actual

[1] The two other main areas of unconventional monetary policy undertaken by the Bank fall under the broad headings of enhanced liquidity support and actions to address dysfunctional markets (see Bean (2011) for further discussion).
[2] All the Bank of England's asset purchases have been made through the APF, which the Bank originally set up in January 2009 with the Chancellor of the Exchequer's authorisation to buy high-quality assets financed by the issue of Treasury bills and the Debt Management Office's cash management operations. The Fund is fully indemnified by the Treasury, which ensures that the Bank does not incur any costs associated with losses arising from or in connection with its operations.
[3] At the time of the initial announcement in March 2009, the market value of the publically available stock of outstanding UK nominal gilts (the free float) totalled £456 billion and had an average maturity of just under 14 years and an average duration of about 8½ years.
[4] Percentage calculated using the redemption value of gilts purchased and in issue.

purchases themselves through the individual reverse auctions conducted by the Bank. In conditions where markets are functioning efficiently, one might expect economic news to be quickly assimilated into market prices as soon as it becomes available to market participants. But, given the unprecedented nature of the QE policy and market conditions at the beginning of 2009, it seems possible that the effects of QE may have taken longer than normal (days rather than hours or minutes) to get reflected in prices. Market prices may also have reacted to the purchases themselves through the auction programme. This might have been because of temporary flow effects arising from the purchases, related to the ability of market makers to hedge their positions. But the auctions themselves may also have revealed information, relating to the distribution of offers across different gilts and the supply of individual gilts available for purchase that had more persistent effects, particularly if it shed light on the price adjustment necessary to accommodate the stock effect of the purchases. It is therefore possible that news about the stock effects from the QE announcements did not get fully incorporated into gilt prices until the auctions were under way.

By using high-frequency data, we are able to assess the magnitude and timing of the gilt market reaction to QE news. The pattern of the cross-sectional response of individual gilt yields to QE announcements and purchases also allows us to assess the importance of some of the transmission channels that have been suggested to explain the link between central bank asset purchases and government bond yields – the first stage in the transmission of QE to the wider economy. In particular, we examine whether the evidence is consistent with: the duration risk channel (where the removal of aggregate duration from the market leads to investors requiring lower compensation for holding duration risk, as emphasised for example by Gagnon *et al* (2011) in explaining the effects of the Federal Reserve's asset purchases), which implies that the largest yield effects would be concentrated in longer-maturity gilts; and/or with effects associated with the local supply or scarcity channel, associated with market segmentation or 'preferred-habitat' behaviour (of the sort originally proposed by Culbertson (1957) and Modigliani and Sutch (1966)), which would suggest that the largest yield effects would tend to be concentrated in those segments of the yield curve where the largest QE purchases were made.

In order to examine these effects, we conduct econometric analysis both of the announcement effects of the policy and of the effects of the reverse auctions using high-frequency disaggregated data on individual gilts. Our analysis of the Bank's reverse auctions builds on earlier research by D'Amico and King (2010) that used daily data on individual Treasury securities to analyse the effects of the first round of the Federal Reserve's asset purchases. Using intraday data we find divergent effects on gilt yields immediately prior to and after the Bank's reverse auctions. We are also able to incorporate gilt level measures of illiquidity and summary information from the individual auction offers into our analysis, which allows us to investigate the role of liquidity and uncertainty about the underlying value of the auctioned securities in explaining the reaction of yields. Finally, we use a panel of daily gilt yield data to estimate the more persistent effects of the Bank's purchases, after allowing for countervailing effects of fiscal news and improving macroeconomic prospects during 2009.

The rest of this paper is structured as follows. Section 2 reviews the MPC's asset purchase programme as it evolved through 2009 and how the purchases were implemented through

reverse auctions. Section 3 reviews the theory on why asset purchases may affect asset prices and discusses some of the related literature relevant to this study. Section 4 discusses the effects of QE announcements on gilt yields using intraday data. Section 5 describes the impact of the MPC's purchases through an analysis of the individual reverse auctions. Section 6 attempts to measure the more persistent stock effects of the QE purchases, by looking at the impact on gilt yields over the period of the purchase programme. Section 7 provides a brief summary and conclusions.

2 The QE asset purchase programme

As described above, the MPC's QE asset purchase programme was first announced on 5 March 2009.[5] The Committee initially decided to purchase £75 billion of private and public sector assets financed by central bank money, which the MPC press statement[6] noted could take up to three months to complete. It was also recognised that nominal government bonds would be likely to constitute the majority of the overall purchases. These purchases were initially restricted to nominal gilts with a residual maturity of between 5 and 25 years, but this was later expanded to gilts with three years or more residual maturity. The Committee increased the overall purchase target in subsequent months, eventually announcing in February 2010 that it would pause its purchases, which had reached £200 billion, but continue to monitor their appropriate scale. Details of the six key QE announcements during this period, which form the basis for our analysis, are summarised in Table 1.

By the end of January 2010, the Bank's purchases of gilts totalled just over £198 billion, representing nearly 30% of the free float. Relative to the free float, the Bank bought 40% of the 3 to 10 year maturity segment, about 50% of the 10 to 25 year maturity segment, and 15% of the 25 year and over maturity segment. A more finely disaggregated breakdown of the Bank's purchases shows that the Bank's purchases were more evenly spaced across duration than across maturity (see Charts 1 and 2). Moreover, the average duration of gilts purchased (9.4 years) was very close to the average duration of the free float (8.3 years). No index-linked gilts were purchased.[7] And, although the Bank of England did purchase a small amount of corporate bonds and commercial paper as part of its QE programme, the purpose of these purchases was aimed at improving conditions in these markets rather than expanding nominal demand as such (Fisher (2010b)).

[5] Financial markets were given advance warning that the MPC was considering unconventional monetary policy measures when the Bank's February *Inflation Report* was published on 11 February, 2009. The *Report* discussed how asset purchases financed by central bank money could be used to help achieve the inflation target if movements in Bank Rate were not sufficient and, at the press conference to launch the *Report*, the Bank's Governor Mervyn King clarified how such measures might work, saying in answer to one question that 'we will be moving to a world in which we will be buying a range of assets, but certainly including gilts, in order to ensure that the supply of money will grow at an adequate rate to keep inflation at the target' (see www.bankofengland.co.uk/publications/inflationreport/conf090211.pdf).

[6] See www.bankofengland.co.uk/publications/news/2009/019.htm.

[7] Fisher (2010a) explains that the Bank wanted to avoid compounding pressures on UK pension funds, who are big investors in index-linked and long-dated gilts.

Table 1: Key QE announcement dates during 2009-10

Announcement	*Decision on QE*	*Other information*
11 February 2009, 10:30	February *Inflation Report* and the associated press conference gave strong indication that QE asset purchases were likely.	
5 March 2009, 12:00	The MPC announced that it would purchase £75 billion of assets funded by central bank reserves, with gilts likely to constitute the majority of purchases. Gilt purchases restricted to bonds with a residual maturity of 5-25 years. Might take up to 3 months to complete.	Bank Rate reduced from 1% to 0.5%.
7 May 2009, 12:00	The MPC announced that the amount of QE asset purchases would be extended by a further £50 billion to £125 billion. Expected to take another 3 months to complete purchases.	
6 August 2009, 12:00	The MPC announced that the amount of QE asset purchases would be extended by £50 billion to £175 billion and that the buying range would be extended to gilts with a residual maturity greater than three years. Purchases expected to take 3 months to complete.	The Bank announced a gilt lending programme, which allowed counterparties to borrow gilts from the APF's portfolio in return for a fee and alternative gilts as collateral.
5 November 2009, 12:00	The MPC announced that the amount of QE asset purchases would be extended by £25 billion to a total of £200 billion. Purchases expected to take 3 months to complete.	
4 February 2010, 12:00	The MPC announced that the amount of QE asset purchases would be maintained at £200 billion.	The MPC's press statement said that the Committee would continue to monitor the appropriate scale of the asset purchase programme and that further purchases would be made should the outlook warrant them.

Source: Adapted from Joyce *et al* (2011a).

Chart 1: BoE gilt purchases relative to free float by years to maturity (end-Jan. 2010)

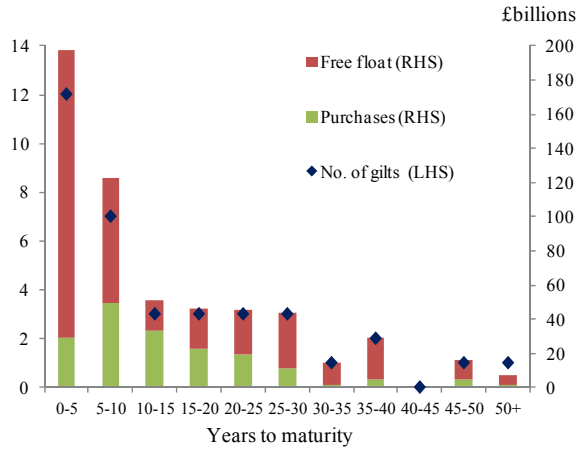
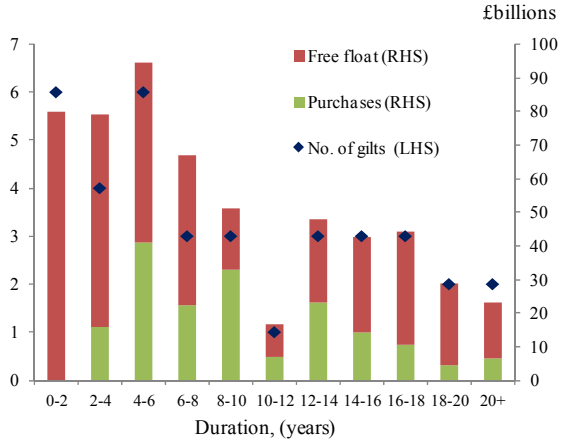


Chart 2: BoE gilt purchases relative to free float by duration (end-Jan. 2010)



2.1 The Bank of England's gilt purchases

The Bank of England began its programme of reverse gilt auctions on 11 March 2009. Initially, two auctions took place each week: one for gilts with a residual maturity of between 5 and 10 years; and another for gilts with a residual maturity of between 10 and 25 years. The Bank offered to purchase gilts with an issue size of £4 billion or greater within each maturity range, with the exception of those that had been issued, or were planned to be issued, by the Debt Management Office (DMO) within seven days.[8]

As the gilt purchase programme continued, the Bank began to build up significant holdings of some gilts. At the end of June 2009 the Bank began to exclude gilts where holdings were at, or close to, 70% of the free float, citing the impact on trading conditions and liquidity.[9] At the MPC's August 2009 meeting, the Committee increased the purchase target to £175 billion and extended the buying range to include all gilts with a residual maturity greater than 3 years. In order to address potential gilt market frictions, the Bank also launched a gilt lending programme. This programme operates in collaboration with the DMO, allowing market counterparties to obtain gilts from the Bank's portfolio in return for a fee and the placement of alternative gilts as collateral. The Bank's market contacts noted that this improved gilt market functioning and the spread between repo rates and the general collateral secured rate normalised somewhat for the few gilts that had been particularly affected (see the box 'Gilt lending facility' in Bank of England (2010)). With the extended purchase range, the Bank added an extra auction, making three in total: a 3-10 year auction, a 10-25 year auction, and a 25 year and over auction. The Bank initially conducted each auction weekly but from November 2009 spread them across two weeks. This auction pattern continued until the £200 billion target was reached at the end of January 2010.

[8] This included sales via mini tender, where the DMO might announce the gilt only days ahead of the tender.
[9] The first gilts to be excluded were the 5% 2014 and the 8% 2021 on 25 June 2009. The eligibility of the former was reinstated on 11 November 2009 following further issuance by the DMO. Two further gilts were excluded from purchases: the 4.675% 2020 on 9 July 2009 (reinstated on 26 October 2009) and the 4% 2022 on 23 July 2009 (reinstated on 12 October 2009).

Over the period 11 March 2009 to 26 January 2010, the Bank conducted a total of 92 reverse auctions (see Table 2). The size of the auctions reduced over time but the auctions were well covered, with the cover ratio (the ratio of all offers received to all offers accepted) varying little over the period of purchases. In general, cover was higher for the shorter-maturity auctions than for the longer-maturity ones. This might have been linked to shorter-dated gilts being more liquid. It might also have reflected the significantly lower duration of the gilts being purchased – banks may have been more willing to place speculative orders, since they could offer a larger notional amount of gilts for a given amount of risk. The weighted average accepted price was lower relative to market prices (a positive gilt yield spread) for the short-maturity gilt auctions and higher (a negative gilt yield spread) for the long-maturity auctions, perhaps related to the same reasons behind the differences in cover ratio. One noteworthy feature of the auctions was the decline over time in the spread between the maximum and minimum accepted yields in each auction - the auction offer dispersion. While the size of the dispersion will have differed between each auction type because of the different characteristics of the securities included in each auction buying range, the fact that the dispersion fell over time for each auction type (even for the shorter-maturity auctions where there was an increase in the buying range from 5-10 years to 3-10 years) might suggest that uncertainty around the clearing price in the auctions decreased, perhaps consistent with some learning behaviour (something we return to in our econometric analysis of the auctions in Section 5).

Table 2: Bank of England gilt auction key statistics (average across auctions)

Maturity bucket	Period	Number of auctions	Cover ratio	Total bids (proceeds) £bn	Allocation (proceeds) £bn	Clearing spread (the weighted average accepted yield to market yield (bp))	Auction offer dispersion (spread between maximum and minimum accepted yields (bp))
3-10-year (5-10 for Mar-Jul)	Mar-Jul	21	3.2	9.1	2.9	0.3	4.0
	Aug-Jan	17	3.5	5.2	1.5	0.7	1.6
	All	38	3.3	7.4	2.3	0.4	2.9
10-25-year	Mar-Jul	20	2.2	6.6	3.0	-0.5	4.0
	Aug-Jan	17	2.2	3.3	1.5	-0.4	1.9
	All	37	2.2	5.1	2.3	-0.5	3.0
25-year +	Aug-Jan	17	1.9	2.9	1.5	-0.2	1.9
All eligible gilts	Mar-Jul	41	2.7	7.9	3.0	-0.1	4.0
	Aug-Jan	51	2.5	3.8	1.5	0.0	1.8
	All	92	2.6	5.6	2.2	0.0	2.8

2.2 The format and timing of the gilt auctions

The Bank's auctions were structured as multiple-price (discriminatory) reverse auctions, with competitive and non-competitive elements.[10] The competitive bidders were allowed to submit multiple bids, which consisted of both price and quantity. The non-competitive bids were allocated in full at the weighted average accepted price set in the competitive auction. The minimum bid size was £5 million for the competitive auction and £1 million for the non-competitive auction. In practice, purchases through the non-competitive auction process were relatively small, accounting for only 1% of the total.

The size of each week's auctions and the gilts being purchased were announced at 4pm on the Thursday of the week before each auction. The Bank made few changes to the timing and sizes of auctions for each maturity range of gilts, so auction participants could know with a fair degree of certainty which gilts the Bank would be purchasing weeks ahead of each Thursday announcement.

Non-competitive bids could be submitted until 12 noon on the day of the auction. The size of competitive auction was then announced at 1pm. The competitive auction took place between 2.15pm and 2.45pm, with participants able to submit bids within this time.

At the 2.45pm auction close, the Bank compared the yield for each competitive bid with gilt mid-yields quoted on the DMO's Bloomberg page, in order to rank them from highest to lowest. The competitive bids were then allocated, from highest to lowest, with a partial allocation for the lowest accepted bid if this was necessary to meet the purchase target. The Bank did not limit the share of each gilt purchased in an auction. Since the majority of trading activity in the gilt market continues until 4.30pm, which is generally thought of as the close of business, there was time after each auction for the market to react to any perceived news in the results.

3 Linking asset purchases to asset prices: theory and previous evidence

In a review of the Bank of England's QE policy, Joyce et al (2011b) emphasise three main channels through which asset purchases might affect the wider economy: higher asset prices (through portfolio rebalancing effects or falls in liquidity premia asset prices increase, in turn boosting wealth and reducing the cost of borrowing), signalling effects (eg by demonstrating that the monetary authorities are willing to do whatever it takes to meet the inflation target), and increased bank lending (in response to the boost to commercial bank reserves). Of these channels, the MPC has given most emphasis to the asset price channel operating through a portfolio rebalancing effect (see Dale (2010), Bean (2011) and Fisher (2010a)). Given this emphasis, studying the impact of asset purchases on the gilt market provides the obvious starting point for assessing the policy's effectiveness, as it seems very likely (if not a strict prerequisite) that the QE intervention should have had a significant and immediate impact on the market where the purchases were actually made.

[10] All firms authorised for the purposes of the Financial Services and Markets Act were eligible for the non-competitive auction with the exception of firms eligible for the Bank's gilt purchase open market operations. The latter group of firms were eligible for the competitive auction.

The theoretical origins of the portfolio balance channel go back to Tobin (1961, 1963 and 1969) and Brunner and Meltzer (1973) among others, who showed how imperfect asset substitutability could lead to quantity effects on asset prices. For QE to reduce gilt yields through a portfolio balance effect requires that assets - in this case, money and gilts - are viewed as imperfect substitutes by investors. The logic is that, following a shock to asset supply, there needs to be a change in expected excess rates of return/risk premia in order to restore equilibrium.

As demonstrated by Eggertsson and Woodford (2003), however, imperfect substitutability on its own is insufficient to generate portfolio balance effects in standard New Keynesian macro models. In these kinds of dynamic stochastic general equilibrium (DSGE) model, QE can only affect behaviour by changing agents' beliefs about the path of future interest rates or inflation. One implication that is sometimes drawn from this is that the central bank should commit itself to a path for future policy rates. The reason why QE can only be effective through such a 'signalling channel' is that these kinds of model are based on a representative agent and assume the existence of state-contingent markets. The result is that private agents in the model effectively consolidate the private and public sector balance sheets into their decision making. So, if the monetary authorities exchange reserves for interest rate sensitive public sector debt, the private sector anticipates that its taxes will be correspondingly sensitive to the additional interest rate risk. This in turn reduces demand for public sector debt by the same amount, so prices/returns do not need to adjust. This effect is very similar to Ricardian equivalence and does not hold in more general cases where there are credit constraints, limited financial market participation or distortionary taxes. For example, Andrés, López-Salido and Nelson (2004) incorporate a form of limited participation into a DSGE model, by introducing agents with different preferences for long-term bonds, that generates effects from QE-type asset purchases.[11]

Imperfect asset substitutability is consistent with so-called preferred-habitat theories (Modigliani and Sutch (1966), Culbertson (1957)), where investors have a preference for a particular segment of the yield curve. Vayanos and Vila (2009) develop such a model where the preferred habitats of investors mean that the supply of bonds affect yields, even in the presence of arbitrageurs who do not share those preferences, provided the latter are risk-averse or capital constrained. The source of imperfect substitutability could be any characteristic that makes an asset preferred, including convention and regulation. If there are preferred habitats then the demand for these preferred securities is underpinned, giving scope for quantities to matter in their price determination. The consequence of the central bank buying up government bonds is that it creates scarcity in these assets, pushing up their prices/reducing their yields. This scarcity effect is sometimes referred to as a 'local supply effect' because, to the extent that the actions of other investors (arbitragers in the Vayanos and Vila model) are unable to offset fully the effects, the main price effects should be concentrated (localised) in the bonds being purchased.

In addition to any scarcity effects, bond purchases may directly lead to price changes because of their effect on aggregate duration risk. Gagnon *et al* (2011) emphasise this channel in their analysis of the effects on Treasury yields of the Federal Reserve's large-scale asset purchases (LSAPs); for an opposing view, see Krishnamurthy and Vissing-Jorgensen (2011). The idea is

[11] Harrison (2012) uses a similar approach to incorporate QE effects into a DSGE model.

that the central bank's purchases of long-duration assets, like medium to long-term gilts, reduce the average duration of the stock of government bonds held by the private sector and this leads to a reduction in the premium required to hold duration risk. In the Vayanos and Vila model, the effect comes about because arbitrageurs will consequently need to hold a smaller quantity of duration risk. This reduction in duration risk leads to a fall in the market price of duration risk, reducing term premia and hence yields. The existence of the duration risk channel arises from the behaviour of the marginal investor and is not restricted to models with preferred-habitat investors. In contrast to local supply effects, which might be expected to show up mainly in the bond maturities being purchased, a change in the price of duration risk would be expected to increase the price of all long-duration assets, with the effects increasing with the duration (maturity) of the asset.

If asset purchases work through portfolio balance effects, and more specifically through scarcity or duration risk channels, then we would expect them to have persistent effects on yields, as their impact depends on the relative size of the shock to asset stocks. So, unless the effects of asset purchases on relative asset supplies are expected to be unwound (eg through asset sales, the assets maturing, or other quantities adjusting), they should continue to be reflected in asset prices. Moreover, to the extent that asset markets - and in particular the gilt market - operate efficiently, we would expect these portfolio balance effects to be quickly incorporated into prices as soon as the relevant news about future asset purchases is made publicly available. It seems possible, however, that the extraordinary nature of the QE purchases, and the fact that markets were not functioning normally in early 2009, might have meant that these effects took longer to be fully incorporated into market prices than would otherwise have been the case. Indeed it is conceivable that the full effects might not have been incorporated until asset purchases were actually being made through the auction programme and it became clear what change in yields would be necessary to accommodate the change in asset stocks.

In addition to any impact through changing asset stocks, QE may also affect gilt yields through so-called flow effects associated with the purchases themselves. There is a large microstructure literature that documents flow effects on asset prices across a range of markets, suggesting that even in normal circumstances asset prices may be affected by trading activity (see eg Babbel *et al* (2004)). In the case of QE, the presence of the central bank in the market as a large buyer may improve market functioning, particularly in stressed market conditions, and thereby reduce premia for illiquidity by making it easier for investors to sell assets when required. These liquidity premia effects might normally be expected to be temporary and limited to the period of purchases but other effects might be more persistent.

The traditional literature on price determination in dealership markets generally refers to three sorts of theory to explain the spreads charged by market makers: transaction costs (Demsetz (1968) and Tinic (1972)) reflecting the effect of trade volumes on processing costs; inventory effects (Stoll (1978) and Ho and Stoll (1981)) reflecting the riskiness of holding a suboptimal portfolio; and asymmetric information effects (Glosten and Milgrom (1985) and Kyle (1985)) that may arise as compensation for the possibility of trading with an informed trader.[12] Effects

[12] For a review of this literature, see Proudman (1995).

through transaction costs and inventories are more likely to lead to temporary effects on asset prices, while information effects might lead to more permanent effects, as order flow provides information to traders about equilibrium prices. Though asymmetric information is generally thought to be less relevant in the more transparent case of government bond markets, it seems possible that this factor may have been important in the case of the Bank's QE purchases, where there was more uncertainty about the effects of the purchases. In this case, the asymmetry relates not to the possession of different information but to the differing ability of market participants to process the implications of the QE news. If this kind of information effect were important then it is possible that both the QE announcements and the gilt purchases themselves may have had protracted effects on yields.

In terms of empirical evidence, a number of other papers have looked at the reaction of asset prices to news about large-scale asset purchases (examples for the United States are Gagnon *et al* (2011), Krishnamurthy and Vissing-Jorgensen (2011) and Neely (2010) and, for the United Kingdom, Meier (2009) and Joyce *et al* (2011a)), though to our knowledge, our study is the first to use intraday data on the whole cross-section of gilt yields to examine market reactions to the UK QE policy announcements and purchases. There is a relatively large literature that has looked at the effect of conventional Treasury auctions on asset prices (see eg Sundaresan (1994) for a review of the earlier US literature and Breedon and Ganley (2000) for the UK evidence). A more recent paper by Lou, Yan and Zhang (2011) finds that even in the highly liquid US Treasury market there are significant price declines ahead of Treasury auctions, reflecting hedging by primary dealers which is not matched by compensating capital flows from end-investors.[13] In the context of the QE auctions, this would suggest that yields would fall before each auction, but this effect would be offset in subsequent days, as liquidity returns. Unsurprisingly given their rarity, there has been relatively little research on the effects of reverse government bond auctions (D'Amico and King (2010) look at the Federal Reserve's LSAPs and Han, *et al* (2007) examine the US Treasury buybacks in 2000). In this respect, our work is closest in spirit to D'Amico and King, but differs to the extent that we directly incorporate measures of liquidity and price uncertainty and also examine intraday price movements before and after each auction.

4 Announcement effects

To the extent that financial markets were efficient in processing news about QE then we might have expected the impact of QE news to have been quickly incorporated into prices when it was released, rather than being delayed to when the QE purchases were made. This logic motivates adopting an event study approach to analysing the impact of QE. Using this method, Joyce *et al* (2011a) examine the reaction of gilt yields to the six QE news events discussed in Section 2, finding that 5-25 year yields fell cumulatively by around 100 basis points over a two-day window (a similar approach is used in Gagnon *et al* (2011) to quantify the effects of the Fed's LSAP programme). In this section we use high-frequency intraday data to examine the market reaction to the same announcements about QE across different gilts. The intraday data we use

[13] This relates to an emerging literature that explains asset price anomalies in terms of slow-moving capital. See Gromb and Vayanos (2010) for a broader review of the literature on the limits of arbitrage.

were obtained from Tradeweb, whose gilt data are sourced directly from gilt-edged market makers. Although deals undertaken directly via Tradeweb only accounted for around 5% of gilt market turnover over our sample period, these data seem to be the best available source of high-frequency price data on individual gilts. Banks that contribute quotes to Tradeweb would have accounted for over 90% of gilt market trades. The continuous intraday data set we obtained were originally provided in the form of indicative bid and ask composite quotations, which we converted into 5 minute observations by taking the average of the last bid and ask yield/price quotations in each 5-minute interval. The data for yield-to-maturities used are based on average bid and ask quotations. All our key results on local supply and duration effects, however, are robust to using daily DMO yield-to-maturity data.

To provide some context for our analysis, Table 3 uses Bank of England zero coupon data to illustrate the two-day reactions to the six pieces of QE news discussed in Section 2. The two-day yield movements following the publication of the Bank's *Inflation Report* and associated press conference in February 2009[14] and the announcement of the commencement of QE purchases after the March MPC meeting were in the 1% percentile of yield moves during the period between August 2007 and February 2010. These announcement effects dominate the others and in fact the size of the overall reaction summing over all the announcements is quite robust to excluding QE news that - according to the contemporaneous Reuters survey of economists - was either less than expected (May) or broadly in line with expectations (November and February). Another striking feature of the data is that the largest reactions were at longer maturities, with the reaction of the 20-year spot yield about 120 basis points compared to a 55 basis point reduction in 5-year spot rates.

[14] Since part of the February 2009 reaction at short maturities may have reflected the increased expectation of a further cut in Bank Rate, we show the adjusted yields used by Joyce *et al* (2011a). See also notes of Table 3.

Table 3: Reaction of ZC nominal gilt yields to QE news over a 2-day window (bp)

Date	*3 year*	*5 year*	*10 year*	*15 year*	*20 year*	*25 year*	*30 year*	*5-25 year*
(1) 10 Feb, 2009 (adjusted[+])	-44*** (-25**)	-40*** (-26***)	-34*** (-27***)	-24*** (-19**)	-15** (-12**)	-13** (-10*)	-13** (-10*)	-25*** (-19**)
(2) 4 Mar, 2009	-8	-34***	-68***	-82***	-89***	-76***	-54***	-75***
(3) 6 May, 2009	7	9	10	5	1	2	6	5
(4) 5 Aug, 2009	-3	-4	-3	-15**	-26***	-28***	-26***	-15
(5) 4 Nov, 2009	-2	4	10	8	5	3	2	7
(6) 3 Feb, 2010	-5	-4	-2	-1	0	0	-1	-1
Cumulative change 1-6	-54**	-70***	-88***	-109***	-124***	-112***	-86***	-104***
Cumulative change 1-6, Feb adjusted[+]	-35	-55***	-80***	-104***	-121***	-109***	-83***	-97***

[+] Part of the fall in yields following the February 2009 announcement may have reflected the market's greater certainty that there would be a Bank Rate cut in March 2009. The figures reported in parentheses are adjusted to take account of this effect: spot rates for 12 February were recalculated with 25 basis points subtracted from the underlying instantaneous forward rates between zero and five years on a sliding scale, as in Joyce *et al* (2011a). ***/**/* denotes statistical significance at the 1%/5%/10% percentile level from 2-day and 12-day changes over the period August 2007 to February 2010.

4.1 Intraday announcement reactions

The use of intraday data allows us in principle to measure the market reaction more accurately than studies based on daily data. We can date the reaction from the precise time the relevant news became available to the market, rather than the close of business the day before. And the pattern of the subsequent move in yields may suggest whether it was consistent with a single news shock, or whether it also incorporated reactions to other news events.

Chart 3 shows the intraday reaction of yields on six gilts - chosen to span the maturity spectrum - to the six pieces of QE news (the results are very similar for other gilts with similar maturities). Cumulative yield reactions over different time windows including our preferred window, as explained below, are provided in Table 4.

After the first event - the publication of the February 2009 *Inflation Report* and associated press conference at 10.30am on 11 February - the data show there was a sharp initial reaction across the yield curve, particularly at short maturities (Chart 3 (a)). Some of this reaction can be accounted for by the market's expectation that it was more likely that the MPC would cut Bank

Rate at its March meeting to 50 basis points, [15] but there also seemed to be an expectation that the Bank would purchase shorter-maturity gilts (see eg *Financial Times* (2009a)). By about 12 noon the decline in yields stabilised, though there were further small declines at short maturities until close of business at 4.30pm. On the same day, European and US government bond yields fell following Tim Geithner's widely anticipated speech on the US administration's strategy on dealing with the financial crisis, so we cannot entirely rule out that there may have been some reaction in gilt yields to international news. But after markets opened the next day there were further reductions in gilt yields, again concentrated at shorter maturities but not limited to them, and yields across the curve drifted lower until the end of the day. There was little further news on the day,[16] and the fact that falls in UK gilts were larger than in other markets suggests that the market was still digesting news in the *Inflation Report*. Given the protracted reaction of gilt yields, it seems appropriate to measure the market reaction to the QE news to close of business on 12 February.

The MPC's official announcement on 5 March 2009 that it would begin asset purchases led to an immediate fall in gilt yields, especially at longer maturities (Chart 3(b)). Very short-maturity yields (eg the 5% 2012 gilt yield in Chart 3(b)) fell by much less and then rebounded, apparently reflecting the previous perception that the Bank would buy short-dated gilts rather than the medium to long maturities referred to in the 12 noon MPC press release. Yields at most other maturities fell until 2.15pm, when a market notice was issued by the Bank clarifying that the purchase range would be limited to gilts with residual maturity of between 5 and 25 years. This led to a rise in longer, and to a limited extent shorter, maturity yields (something we return to in Section 4.2). Government bond yields on the day were also lower in the United States, with the main driver probably being downward revisions to forecasts for the non-farm payrolls figure to be released that Friday. And European government bond yields fell after the European Central Bank (ECB) announced a 50 basis point reduction in its policy rate. So again we cannot totally rule out that gilt yields were influenced by international events, but the international moves were less marked. The further fall in gilt yields the next day seems to suggest that the market was still digesting the MPC's asset purchase announcement. On that day there was mixed international news. European bond yields fell further, possibly in response to the previous day's ECB rate reduction. US Treasury yields, however, moved slightly higher across the curve following a non-farm payrolls outturn that was in line with Consensus forecasts, but stronger than had recently been rumoured. Overall, given the continuing response of gilt yields during the day after the announcement, it again seems appropriate to measure the market reaction to QE to close of business on the second day.

The £50 billion extension to the MPC's purchase programme announced on 7 May 2009 had been widely anticipated but led to an immediate fall in gilt yields across the curve, though this was subsequently reversed within the hour (Chart 3(c)). By the end of the day, however, yields recorded modest falls that mirrored the initial reaction to the announcement. Yields on the following day were likely to have been affected by the release of US bank stress test results

[15] The calculations reported in Table 3 would suggest that the greater certainty of a Bank Rate cut in March was not the dominant factor driving the fall in yields, even at shorter maturities.

[16] Moody's released a report examining how much debt Aaa rated sovereigns could issue before ratings would be affected. It placed Ireland and Spain in the 'vulnerable' group, and the United States and United Kingdom in the 'resilient' group.

(published late the night before) and a non-farm payrolls release. This suggests that looking at the reaction of yields over a shorter one-day window is more likely to be appropriate.

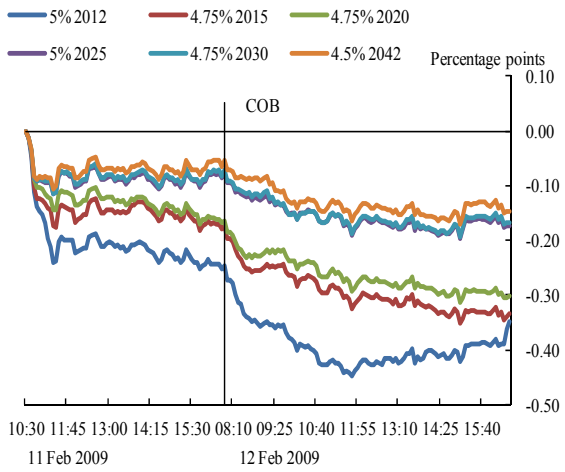
The decision at the 6 August 2009 MPC meeting to expand asset purchases by a further £50 billion and to extend the maturity range of purchases led to initial falls in yields across the curve, particularly at longer maturities (Chart 3(d)). These moves were partly reversed in the early afternoon, particularly at shorter maturities not included in the new buying range (with the yield on the 5% 2012 reversing its initial fall). By close, yields with residual maturities of three years and over were 10 to 15 basis points down on the day. US government bond yields were broadly unchanged over the same period, suggesting that the UK move was not driven by international developments. On the next day gilt yields opened lower, suggesting that the MPC decision was still affecting them. In the afternoon, however, stronger-than-expected US payrolls data helped push up yields, suggesting that the market reaction to the QE announcement is best measured by a shorter window extending out to midday on the day after the announcement.

The decision on 5 November 2009 to expand the asset purchase programme by a further £25 billion over the next three months to a total of £200 billion was broadly in line with market expectations, as measured by the Reuters poll of economists. Yields rose modestly, perhaps bolstered also by UK manufacturing figures for September that were stronger than expected (Chart 3(e)). The movements of yields showed no clear pattern and it seems appropriate to measure the reaction to the announcement in terms of a narrow one-hour window after the announcement. The decision on 4 February 2010 to pause the programme was also widely expected and lead to a very small rise in yields across the curve (Chart 3(f)). The subsequent fall and volatility in gilt yields over the next day and a half most likely reflected a number of other unrelated factors, including concerns about the fiscal position in peripheral European countries and the pickup in US unemployment. In this case, it also seems appropriate to measure the market reaction by the initial one-hour response.

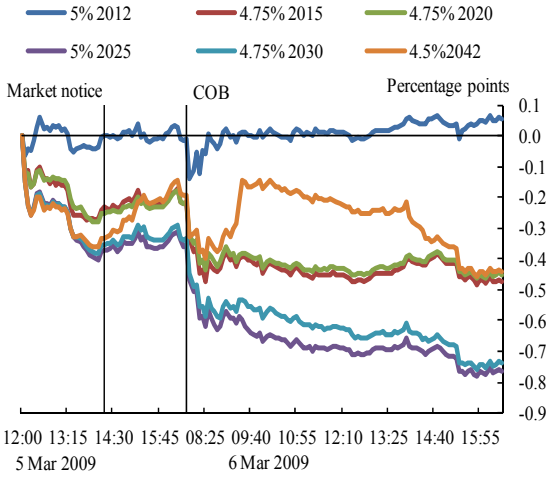
The result of summing up the market reactions over the windows we have suggested produces overall effects (in the final row of Table 4) that are very similar to results using two-day market reactions based on Bank of England zero coupon yield curve data (see Joyce *et al* (2011a)). On balance, the gilt yield moves following QE news events suggest an overall reaction of close to 100 basis points on average across medium to long-term maturities, with the bulk of this effect skewed towards longer maturities of 15 and 20 years. There is obviously room for disagreement on the precise judgements we have made, but it is difficult to see another cut of the data leading to very different results.

Chart 3: Cumulative changes in yield to maturities following QE announcements

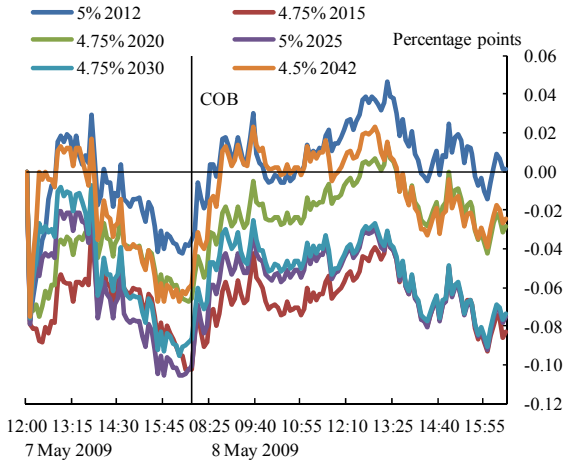
(a) 11 February, 2009



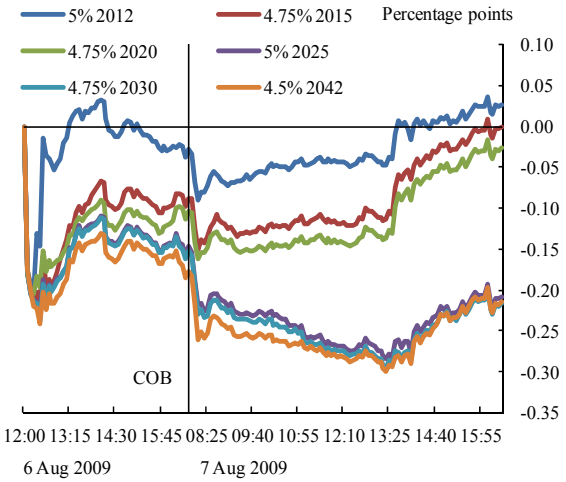
(b) 5 March, 2009



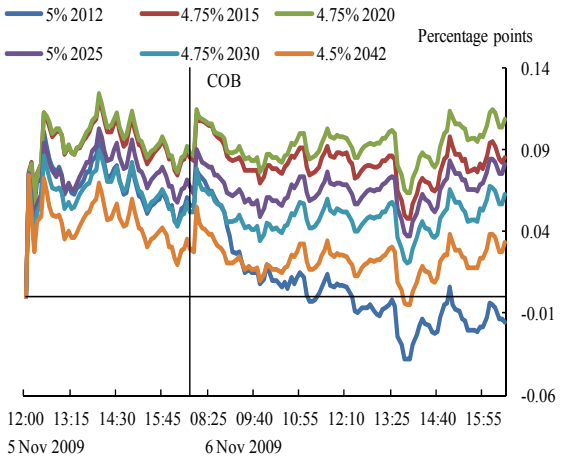
(c) 7 May, 2009



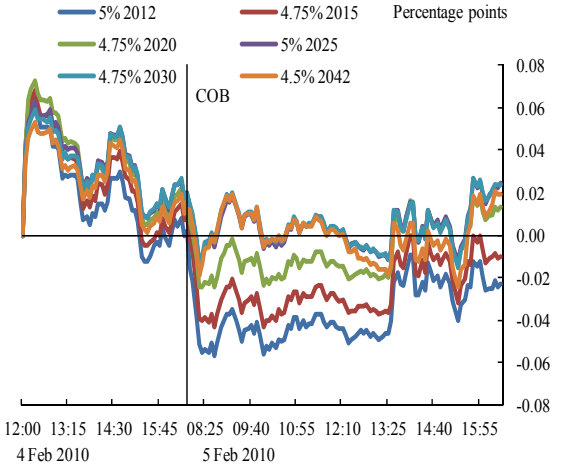
(d) 6 August, 2009



(e) 5 November, 2009



(f) 4 February, 2010



Source: Tradeweb.

Table 4: Changes in gilt yields following QE news over different time intervals (bp)

Window	UKT, 5% 2012	UKT, 4.75% 2015	UKT, 4.75% 2020	UKT, 5% 2025	UKT, 4.75% 2030	UKT, 4.5% 2042
(1) 11 Feb 2009 (10:30am):						
Plus 1 hour	-20	-14	-12	-8	-8	-7
Cob	-25	-17	-16	-8	-7	-5
Cob + 1 day	-35	-34	-30	-17	-17	-15
Reaction	-35	-34	-30	-17	-17	-15
(2) 5 Mar 2009 (12:00pm):						
Plus 1 hour	3	-15	-14	-22	-22	-23
Cob	-1	-22	-22	-35	-33	-19
Cob + 1 day	5	-47	-45	-77	-74	-44
Reaction	5	-47	-45	-77	-74	-44
(3) 7 May 2009 (12:00pm)						
Plus 1 hour	2	-6	-4	-2	-1	1
Cob	-4	-10	-7	-10	-9	-6
Cob + 1 day	0	-8	-3	-8	-7	-2
Reaction	-4	-10	-7	-10	-9	-6
(4) 6 Aug 2009 (12:00pm)						
Plus 1 hour	-4	-16	-16	-19	-19	-20
Cob	-3	-9	-10	-15	-15	-18
Cob + 1 day	3	0	-3	-21	-22	-22
Reaction	-4	-12	-14	-27	-28	-28
(5) 5 Nov 2009 (12:00pm):						
Plus 1 hour	7	10	10	7	6	5
Cob	6	9	9	7	5	3
Cob + 1 day	-2	9	11	8	6	3
Reaction	7	10	10	7	6	5
(6) 4 Feb 2010 (12:00pm)						
Plus 1 hour	4	5	6	5	5	4
Cob	0	1	2	2	2	1
Cob + 1 day	-2	-1	1	2	2	2
Reaction	4	5	6	5	5	4
Cumulated reaction over (1) to (6)						
Plus 1 hour	-8	-36	-30	-39	-39	-40
Cob	-26	-49	-45	-59	-57	-43
Cob + 1 day	-31	-82	-68	-112	-111	-77
Reaction	-26	-88	-81	-119	-116	-84

Source: Tradeweb.

4.2 Implications for QE transmission channels

As well as shedding light on the precise market reaction to news on QE purchases, analysis of the disaggregated intraday data following QE announcements can also tell us about the nature of the transmission of QE through to gilt yields. Chart 4 shows the cross-sectional relationship between yield movements after each announcement and each gilt's duration, where yield changes are shown over the first hour after each announcement and over our preferred window in cases where this is longer. The most interesting events from this perspective are the February 2009, March 2009 and August 2009 announcements, when the largest market reactions occurred. For these announcements, we also report variants of the following simple cross-sectional regression as a means of describing the data:

$$\Delta Y^i = \alpha + \sum_{j=1}^{3} \beta_j \, LS^{i,j} + \beta_4 DUR^i \qquad (1)$$

where the dependent variable, ΔY^i , denotes the change in the gilt *i* yield calculated over our preferred window after the relevant QE announcement.

The three right-hand side *LS* variables in this regression attempt to capture effects coming through a local supply, or scarcity, channel. They are:

- 'purchase range': this is an indicator variable, taking the value 1 if the gilt is included in the announced or expected purchase range and 0 otherwise. If a gilt is included in the purchase range then we would expect to see a larger fall in its yield, so the coefficient on this variable should have a negative sign.
- 'newly eligible': this is an indicator variable that takes the value 1 if the gilt was added to the purchase range in the latest announcement, the value -1 if it was excluded, and zero otherwise. We would expect the fall in yields to be greater for gilts that have been newly added to the purchase range, so this variable should also be negatively signed.
- 'duration gap': this variable is the difference in years between a given gilt's duration and the duration of the closest gilt included in the purchase range.[17] This variable captures the idea that the price effect on gilts not being purchased will be greater for those gilts that are more substitutable for those in the purchase range. To the extent that duration provides a measure of the substitutability between gilts, we would expect to see a smaller fall in yields for gilts that have a larger duration gap, so the coefficient on this variable would be expected to be positive.

The final variable included in the regression, *DUR*, is the gilt's 'duration'. If the duration risk channel is important then the fall in yields should be increasing in the gilt's duration, so β_4 should have a negative sign. Finally, it is worth mentioning that the constant term in the regression will also pick up average scarcity effects from QE that reduced yields across the curve, so we might expect α, the constant term in the regression, to be negative. It needs to be recognised, however, that this is a simple regression and omits other potential factors (eg the signalling effect of QE on Bank Rate expectations) that may also be relevant in explaining the cross-sectional reaction of yields.

As discussed above, the immediate gilt yield reaction to the February announcement was greatest at short to medium maturities (Chart 4(a)). Though this may have partly reflected greater certainty of a further Bank Rate cut to 0.5% in March 2009, this would not account for the sharp discontinuity which occurs between the size of the fall in yields on the adjacent 8% 2021 and the 5% 2025 gilts. An obvious rationalisation is that the market expected the Bank to concentrate its purchases at short to medium maturities and that the large gap between the 8% 2021 and 5% 2025 gilt would be used to define the edge of the purchase range. The consequential yield movements would therefore reflect local supply effects. The fact that the magnitude of the fall in yields seems to decline with duration beyond the 8% 2021 gilt suggests that gilts with duration closer to this gilt (at the edge of the expected purchase range) were

[17] The reported results use the Macaulay measure of duration. Using modified duration instead leads to negligible differences. For an explanation of these common duration measures see, eg, Campbell *et al* (1997).

deemed more substitutable, also consistent with a market segmentation story. On the face of it, this pattern of yield reactions seems difficult to rationalise with the duration risk channel discussed in Section 3, as the size of the fall in yields seems to decline with duration. This is confirmed by the regression results for the February announcement shown in Table 5, where we have assumed the expected purchase range included all gilts out to the 8% 2021 gilt. Whether the gilt is in the implied purchase range is the only statistically significant factor. The results also show that the duration gap is positively signed (as expected), as is duration (inconsistent with the duration risk channel), but both variables are statistically insignificant. On balance, these results suggest that local supply effects dominated in the immediate reaction to the February news.

The March announcement provides another interesting case study. When the initial QE announcement was made, the MPC statement specified only that the Bank would buy 'medium- and long-maturity conventional gilts in the secondary market' and the precise purchase range was only clarified just over two hours later at 2.15 pm, when the Bank issued a market notice explaining that it would buy gilts with residual maturities between 5 and 25 years. Comparing the initial reaction of yields with the later reaction provides an indication of the effects of the clarification (Chart 4(b)). The reaction after one hour suggests that the market had previously expected the Bank to buy shorter-maturity gilts, since their yields rose rather than fell. Yields on medium to long-maturity gilts fell by broadly similar amounts, though gilts with higher duration fell by slightly more. This pattern could be consistent with a duration risk channel, but the reaction to the subsequent market notice would also be consistent with local supply effects. After their initial falls, yields on gilts with above 25 years' maturity (with duration of 15 years and above) rose relative to gilts in the buying range, though yields on long-duration gilts within the range clearly fell by more overall. The regression results reported in Table 5 suggest that the pattern of yield reactions over the period to close of business the day after the announcement was consistent with both local supply and duration risk channels. The size of the fall in yields overall was larger for gilts with higher duration, larger for gilts in the announced purchase range - more so for gilts that had not been expected to have been included - and smaller for gilts which had the largest duration gaps relative to the edges of the 5 to 25 year purchase range.

Finally, the August announcement provides another example of the relative role of supply effects and duration risk effects. In this case, the market notice clarifying the decision to extend the purchase programme to gilts with maturities of three years and above was issued immediately after the MPC announcement and had a clear impact across the term structure (Chart 4(d)). The largest fall in yields was for gilts in the 3 to 5 year and 25 year and greater maturity ranges, which were previously excluded. This pattern of reactions is also consistent with a local supply story, but the size of the falls in yields does appear to increase in duration, consistent with a duration risk channel. This is confirmed by the regression results in Table 5. The coefficient on whether the gilt was in the new purchase range (purchase range) and whether the gilt had been added to it (newly eligible) are both negative and statistically significant, as is the coefficient on the duration of the gilt. In this case, however, the coefficient on the duration gap was statistically insignificant.

Table 5: Announcement reaction regressions

Change in yields (pp)	11 February 2009	5 March 2009	6 August 2009
Constant	-0.198***	-0.181**	-0.032
Purchase range[+]	-0.141***	-0.148**	-0.087**
Newly eligible	n/a	-0.194***	-0.050***
Duration gap	0.003	0.031**	-0.003
Duration	0.001	-0.020***	-0.007***
Number of observations	30	32	35
Adjusted R^2	0.91	0.96	0.85

***/**/* denotes statistical significance at 1%/5%/10% level.

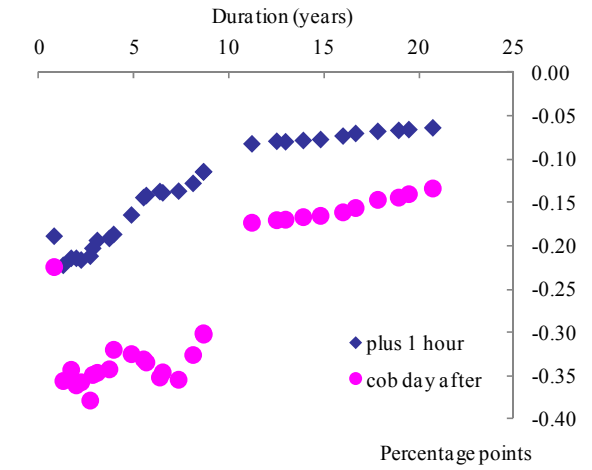
[+] In the case of the February announcement this denotes the implied purchase range (see text).

4.3 Conclusion

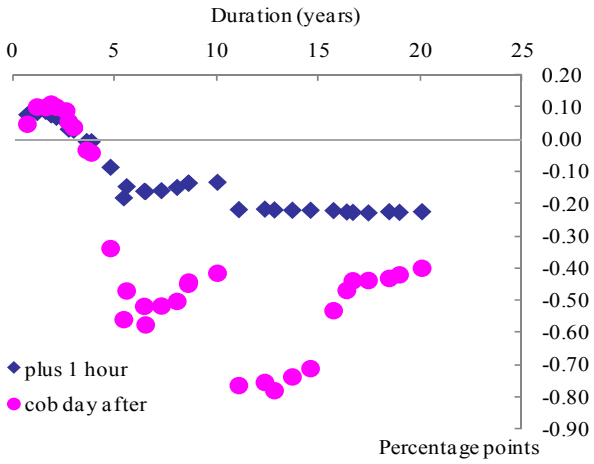
Analysis of the intraday data suggests that the QE announcements took varying amounts of time to be incorporated into gilt yields, with the first announcements taking days rather than hours to be fully priced in. Market reactions varied across the term structure, peaking between 15 and 20 years' maturity, but the overall effects are closely in line with the findings of earlier work based on daily data. The evidence from analysis of the cross-sectional reactions of yields to each of the main QE announcements is consistent with local supply effects (with clear segmentation in the responses) and duration effects (with evidence of larger effects for longer-duration gilts).

Chart 4: Cumulative yield reactions to QE announcements in terms of duration

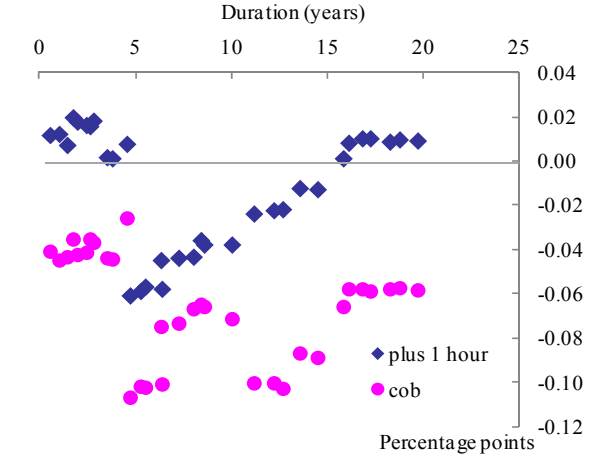
(a) 11 February, 2009



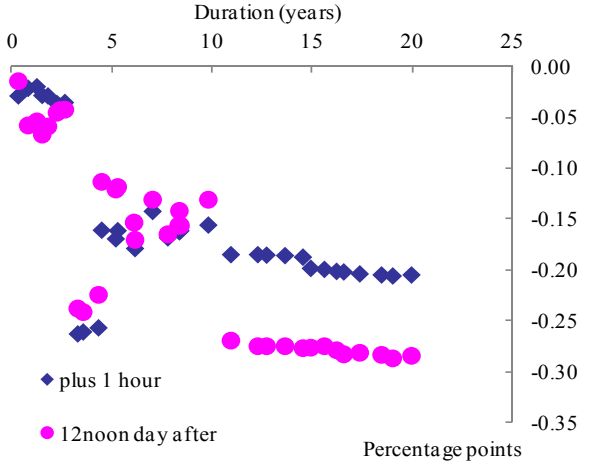
(b) 5 March, 2009



(c) 7 May, 2009



(d) 6 August, 2009



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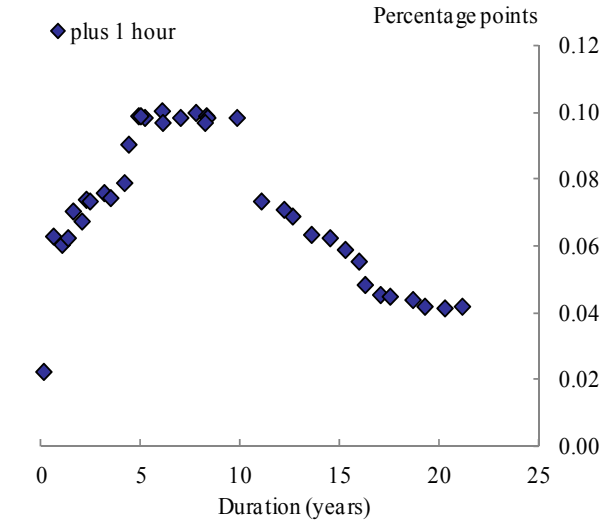
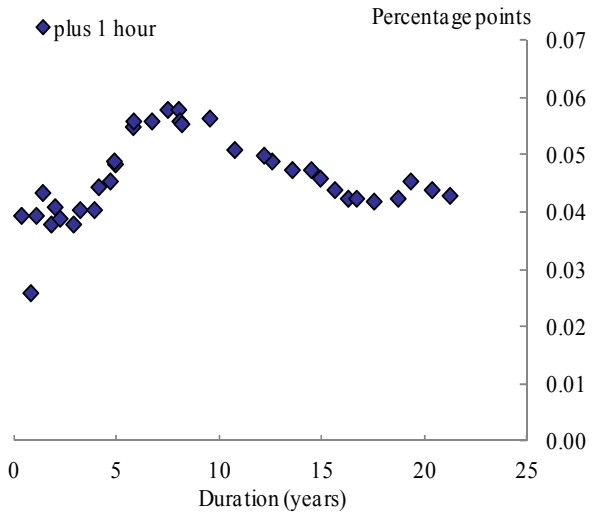


(f) 4 February, 2010



Source: Tradeweb.

5 Auction effects

As discussed earlier, there may be an impact on gilt yields not just when announcements of future QE purchases are made but also when the auctions take place. That may be due to temporary flow effects, related to market makers' limited risk-bearing capabilities. But it might also be because the auctions reveal some information about the distribution of offers across gilts and, more broadly, about the price adjustment necessary to accommodate the change in expected gilt stocks. In order to disentangle these effects, in this section we first run panel data regressions of daily changes in individual gilt yields on quantities purchased, applying a similar methodology to that used by D'Amico and King (2010) in their study of the US Federal Reserve's purchases of US Treasuries during 2009. We then complement this analysis by modelling intraday gilt yield changes around auctions and by augmenting these baseline regressions with additional variables to try to identify how much of the variation in auction yield effects across gilts and time can be explained by changes in liquidity and information gained from the auction process.

To motivate our analysis in the rest of this section, Chart 5 shows the average cumulative change in yields over the period from one day prior to each auction until close on the day after the auction (three days in total) for those gilts eligible for purchase – both on average across all 92 auctions and split into the auction maturity ranges of 3-10 years and 10-25 years. This shows that gilt yields, on average, fell on the morning of each auction but this fall was broadly unwound by the end of the day. At face value, this suggests that the Bank's gilt purchase auctions had a temporary impact on yields that averaged about 2.5 basis points. However, we see from the split by auction type that the fall in yields appears to have been more persistent for purchases of 10-25 year gilts. Chart 6 shows the average change in yields across all 92 auctions for (nominal) gilts that were not eligible to be purchased at those particular auctions or in general because they were not included in the Bank's purchase range – again both on average and split into 3-10 year gilts and 10-25 year gilts. This suggests that, on average, the yields of those gilts were also affected but by less than those gilts eligible for purchase (by around 1.5 basis points), consistent with some (imperfect) substitutability across gilts. However, the standard deviation lines in both Charts 5 and 6 (the dashed lines) show that there was a lot of variation across bonds and auctions.

Chart 5: Average intraday yield moves around auction days for gilts eligible for the auction

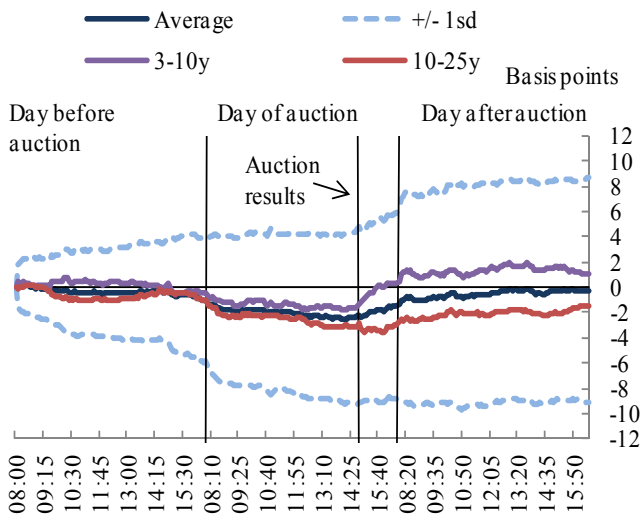
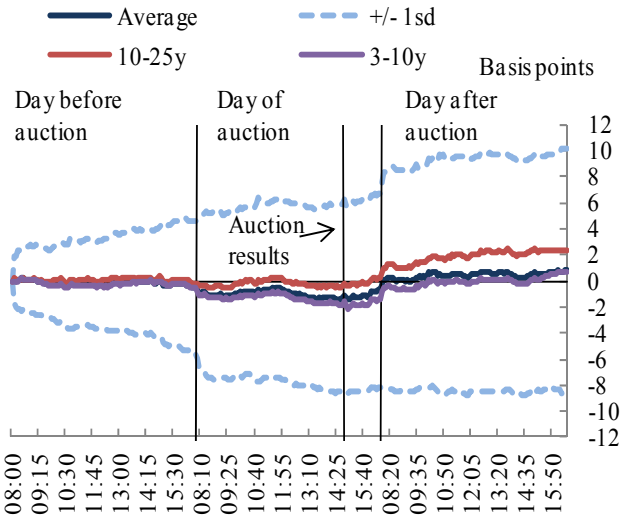


Chart 6: Average intraday yield moves around auction days for gilts ineligible for the auction



Source: Tradeweb.

5.1 Gilt purchase effects

Baseline regression model

We begin by taking a similar approach to D'Amico and King (2010) and regressing the percentage point change in each gilt's yield over the day of each auction on the amount purchased of that gilt ('own purchase') and the quantities purchased of other gilts with nearby durations.[18]

The equation we estimate is therefore:[19]

$$\Delta Y_t^i = \alpha_i + \beta_0 Q_t^{i,0} + \beta_1 Q_t^{i,1} + \beta_2 Q_t^{i,2} + \beta_3 Q_t^{i,3} + \varepsilon_t^i \qquad (2)$$

where ΔY_t^i is the change in the yield of gilt *i* from the close of business on the day before the auction until close of business the following day. The $Q_t^{i,j}$ variables refer to the quantity of gilts purchased in the auction normalised by the free float within two years' duration of gilt *i*. Those quantities are grouped depending on how close their duration is to the gilt whose yield change we are trying to explain, with *j* indicating how close. For own purchases j=0 and, for purchases of gilts with durations within 0-2 years, 2-6 years or 6-14 years of the gilt whose yield is being explained, j=1, 2 or 3 respectively. We also allow for fixed effects, which will capture persistent differences between gilts, such as maturity and duration.

[18] Our approach differs to the extent that D'Amico and King (2010) model percentage price changes rather than yields and use maturity ranges to determine substitutability. We model yields for consistency with the rest of the paper and use duration as it is more commonly used to compare gilts and also because, as shown in Section 2, the pattern of issued gilts is more evenly spaced across duration than maturity.

[19] The fixed effects estimator is used. In each case statistical significance is similar or more significant if cluster-robust standard errors are reported. Time dummies are not used throughout, as their estimates can vary considerably in size and sign between whole and subsample estimation making subsample analysis difficult to interpret. The inclusion of time dummies does not change the whole sample results and typically increases the R^2 to around 60%-80%.

If there were local supply effects from purchases, we would expect the yield impact on a given gilt to be greater the more substitutable it is for the purchased gilt. Provided that the similarity in duration provides a reasonable guide to substitutability between gilts, we would therefore expect the β coefficients to decline as j increases. In addition, if there was a substantial impact from purchases via the duration risk channel, we might expect to see larger coefficients on purchases when the sample is restricted to longer-duration gilts.

In interpreting the regression results that follow, a β coefficient of -1 corresponds roughly to a fall in yields of around 0.8 basis points per £1 billion purchased on average.[20]

Results

Table 6 shows the results of estimating equation **(2)**, split into gilts eligible for purchase in the auction and gilts that were not eligible. The table shows the results for both the full sample period and split into two time periods: March 2009-July 2009 and August 2009-January 2010. The split is intended to identify any time variation in the data, with the break point chosen to coincide with the change in the auction buying ranges described in Section 2.

The results suggest that the pattern of gilts purchased in the auction had a significant impact on the yields of both eligible and ineligible gilts over the auction day. The fact that, in general, the fall in yields was largest for those gilts closest in duration to where purchases were made provides evidence of a local supply effect of gilt purchases on their yields. But the striking overall result is the large decline in the coefficients on purchases in the second half of the sample (which we return to below). However, even when the sample is split into the two periods, the results show that the impact on yields tended to be smaller for those gilts further away in duration to those of the purchased gilts (ie the size of the β coefficients decrease as j in **(2)** increases).

Table 7 splits the full sample into three maturity ranges corresponding to the three purchase ranges used in the auctions. These subsample results suggest that the overall full-sample results were to a large extent driven by the behaviour of the 10-25 year maturity sector, though the largest coefficient on purchase amounts is actually for ineligible gilts in the 25-50 year sector. Further analysis (not reported) shows that, rather than declining over time, the impact from purchases on the yields of these long-dated gilts remained significantly high. For ineligible gilts, the fact that the size of the coefficients on purchases increases with the average duration of the subsample provides some evidence of a duration effect on prices around the auction dates, in addition to the local supply effect mentioned above.

[20] The typical quantity of an individual gilt purchased in one auction was around 0.4% of the size of its 2-year free float amount outstanding, with slightly higher proportions purchased of those gilts close to 10 years to maturity. For nearby gilts, the proportions purchased increase with the relative size of the maturity range – from around 0.3% for 0-2 year substitute gilt purchases to around 0.9% for 6-14 year substitute purchases. The free float within two years' duration of each gilt, used for the normalisation of quantities purchased, averaged around £130 billion but was substantially higher at around £200 billion for those gilts with around 5 years to maturity. For the 2060 gilt this measure is particularly low given the small size of issuance, but excluding this gilt does not materially change the results of the regressions in what follows. On average, the impact on yields per £1 billion purchased is (coefficient*purchase amount)/(average 0-2y free float) = (coefficient*1)/(130) = coefficient*0.8bp.

Table 6: QE purchase effects on gilt yields during March 2009 – January 2010

Auction day yield change	Full sample	March-July	August-January
Eligible			
Own purchases	-0.47	-3.43***	0.43
0-2y purchases	-0.93***	-3.75***	-0.31
2-6y purchases	-0.47*	-3.11***	-0.20
6-14y purchases	-0.04	-2.97	1.43
Number of observations	643	265	378
R^2	0.04	0.14	0.00
Ineligible			
0-2y purchases	-0.65**	-2.25***	-0.01
2-6y purchases	-0.66***	-1.95***	-1.10***
6-14y purchases	-0.64***	-1.47***	-0.51***
Number of observations	2523	1088	1435
R^2	0.03	0.08	0.01

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

Table 7: QE purchase effects on gilt yields, split by auction type

Auction day yield change	<10 years	10-25 years	25-50 years
Eligible			
Own purchases	0.83	-1.55*	0.59
0-2y purchases	-1.68**	-1.40***	-0.19
2-6y purchases	-0.59	-0.97***	-0.19
6-14y purchases		0.08	
Number of observations	280	240	123
R^2	0.02	0.07	0.00
Ineligible			
0-2y purchases	-0.06	-1.00**	-1.07
2-6y purchases	-0.12	-0.75**	-2.38***
6-14y purchases	-0.56***	-0.43**	-0.74***
Number of observations	1419	551	553
R^2	0.02	0.03	0.16

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

Charts 5 and 6 showed that, on average, yields fell in the period leading up to the auction before subsequently reversing. In order to capture these intraday dynamics, we can split the yield change used in the regressions into: (i) the yield change before the auction (from close of business the previous day until 2.45pm) and (ii) the yield change following the auction (from 2.45pm until close of business).

Table 8 shows the results of these intraday regressions for the whole sample, split into those gilts eligible for purchase in the auction and those ineligible as before. It suggests that almost all of the fall in gilt yields associated with the distribution of purchases happened ahead of the actual auction, with little consistency in the post-auction yield moves. Although the precise quantities of each individual gilt to be purchased would have been unknown prior to the auction,

it could be that it was how close a bond's duration was to the auction purchase range that drove the size of the yield effects and this is what is being picked up by the purchase quantity variables – with greater falls in yields ahead of the auction for those gilts closer to the purchase range.[21]

Table 8: Intraday QE purchase effects on gilt yields during March 2009 – January 2010

Intraday yield change	Pre-auction	Post-auction
Eligible		
Own purchases	-0.67	0.20
0-2y purchases	-0.85***	0.09
2-6y purchases	-0.47**	0.00
6-14y purchases	-1.20	1.20*
Number of observations	645	645
R^2	0.04	0.00
Ineligible		
0-2y purchases	-1.00***	0.35**
2-6y purchases	-0.80***	0.05
6-14y purchases	-0.50***	-0.13***
Number of observations	2451	2451
R^2	0.05	0.01

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level

5.2 The impact of liquidity and auction information

The variation in the size and persistence of the effects in Tables 6-8 over time suggest that other factors, in addition to the distribution of purchases, also determined the yield changes around auctions shown in Charts 5 and 6. One factor could be differences in liquidity, which may vary both across gilts and over time. Local supply effects might have been greater for relatively illiquid gilts, as they are less readily substitutable for others. At the same time, as the position of financial institutions improved during 2009, so may have market functioning, reducing the importance of liquidity effects overall. D'Amico and King (2010) emphasise improvements in liquidity as explaining variations in the impact on bond prices from the Federal Reserve's first round of LSAPs of US Treasuries.

A second factor which may also be important, however, is that market participants were uncertain of the change in yields that would be required for the Bank to achieve its purchase targets. That uncertainty might have limited the initial impact on yields from the first QE announcements as markets tried to process the news (as described in Section 3). It was only when the purchases were actually made and the results of the auctions were made available that market participants could infer what yield changes were likely to be consistent with the overall change in the level of gilt supply. Yields may therefore have continued to adjust following the auctions in order to incorporate the full effects of the news on supply. And it seems plausible that these adjustments might have varied across gilts and over time as market participants learnt

[21] Consistent with this, rerunning the regressions with the previous auction results for that purchase range gives similar results.

from the auctions. In short, it is possible that further gilt yield changes were driven not by the distribution of purchases *per se* but by the information revealed in the auctions.

The rest of this subsection investigates the role of these two factors but there are other relevant factors that may also have been important. For example, it seems likely that the risk aversion of market participants may have changed over the period of QE purchases and that this will have influenced the sensitivity of yields to gilt purchases (consistent with the Vayanos and Vila (2009) model of preferred-habitat behaviour). Risk aversion is difficult to measure directly, but it is possible that changes in risk aversion will be picked up to some extent by the measures of liquidity that we use.

Augmented regression model

To try to identify how much yield variation is explained by auction information and liquidity effects, we augment the regressions in the previous subsection with additional variables representing both factors, denoted by A_t and L_t respectively below.

$$\Delta Y_t^i = \alpha_i + \sum_{j=1}^{4} \beta_j Q_t^{i,j} + \sum_{j=1}^{2} \gamma_j A_t^{i,j} + \sum_{j=3}^{4} \gamma_j A_t^{j} + \sum_{j=1}^{3} \gamma_j L_t^{i,j} + \varepsilon_t^i \qquad (3)$$

We include seven further variables. Four $A_t$variables reflect the results of the reverse auctions (three of which were discussed in Section 2). Two of those vary across gilt and across time:

- 'clearing spread': the spread between the average accepted offer for the particular gilt and the market yield at the time of the auction,
- 'gilt offer dispersion': the dispersion of all offers of the gilt, measured by the lambda of a logistic function fitted to the offer curve, as in Préget and Waelbroeck (2005).[22]

And two of the A_t variables are common to each gilt but vary across time:

- 'auction offer dispersion': the dispersion of the clearing spread across all gilts in the auction, measured by the difference between the largest average spread to market yield accepted and the smallest,
- 'cover ratio': the ratio between the total value of gilts offered in the auction and the amount that was purchased.

A further three L_t variables reflect the absolute or relative liquidity of a gilt and so vary across gilt and across time:

- 'fitting error': the difference between the yield on the gilt and a fitted yield curve,
- 'total already purchased': the total amount of a gilt that has already been purchased by the Bank as a proportion of its free float,
- the gilt's 'bid-offer spread', as measured by the average of all Tradeweb quoted bid-offer spreads, as a percentage of price, for that gilt on the day.

Before turning to our regression analysis, it may be helpful to examine what some of these variables look like. Chart 7 plots the clearing spreads in each auction as a time series of box-

[22] Fitting a functional form to the data reduces the impact of large outlying offers relative to a maximum-minimum offer spread measure and is common in some of the government bond auction literature (eg Berg, Boukai and Landsberger (1999) and Özcan (2004))

and-whisker plots. Each box shows the median and interquartile range of clearing spreads in a particular auction. The whiskers show the minimum and maximum spreads. Chart 8 plots the range of these clearing spreads (the auction offer dispersion) broken down by auction type. We can see from these charts that there appears to have been a broad decrease in the variation and volatility of clearing spreads over time, with accepted offers generally closer to market yields in the second half of the sample.[23] This might suggest that a greater market consensus emerged over time about the appropriate change in gilt prices for a given reduction of gilt supply as a result of QE, consistent with the hypothesis that there was some learning over time. Chart 9 plots the cover ratios for the auctions, again split by auction type. On the whole, as discussed in Section 2, auctions for shorter-maturity bonds seem to have had a greater take-up, but there is no clear trend in the data.

Turning to the liquidity variables, Chart 10 shows the range of bid-ask spreads for each gilt across all the auctions as a percentage of the gilt price (the average of bid-ask spreads for quotes posted on Tradeweb during the day of the auction). This shows that, as is common in the gilt market, liquidity tended to be greater for shorter duration bonds but that there was a lot of variation over time. Chart 11 presents the same data across time, showing the range of bid-ask spreads across gilts on each auction day. This chart shows that both average liquidity and the differences in liquidity between gilts declined during the auction period. Chart 12 shows a similar improvement in liquidity over time as measured by the relative pricing of gilts to a fitted curve.

[23] The outlier towards the end of the sample is 6 January 2010. On this day there was reduced trading activity as a result of the Christmas holiday which may have lead to a wider dispersion of offers than normal.

Chart 7: The clearing spread for each gilt in each auction

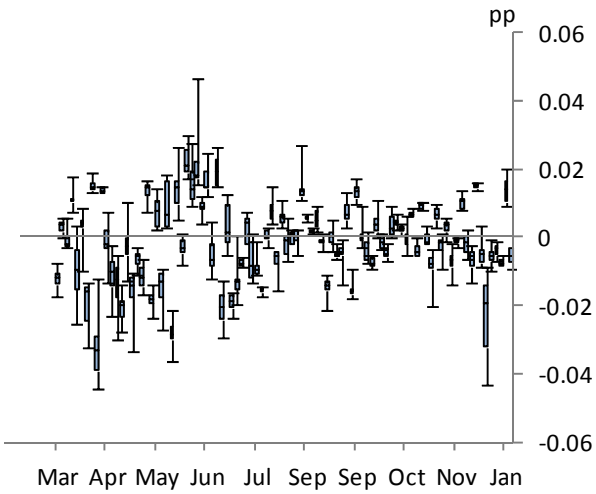


Chart 8: The range of clearing spreads (auction offer dispersion) by auction type

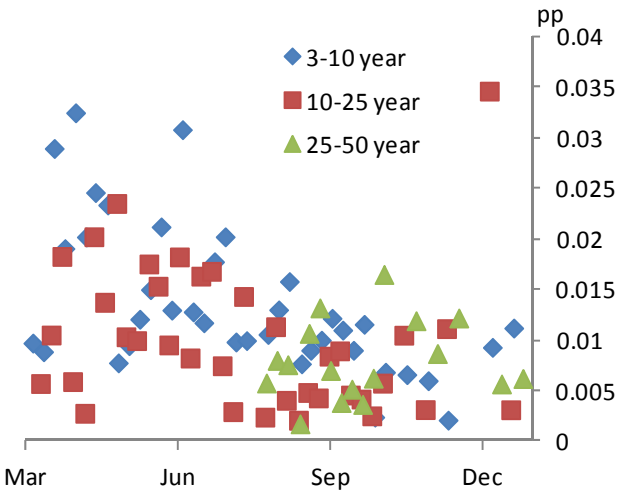


Chart 9: The cover ratio in each auction

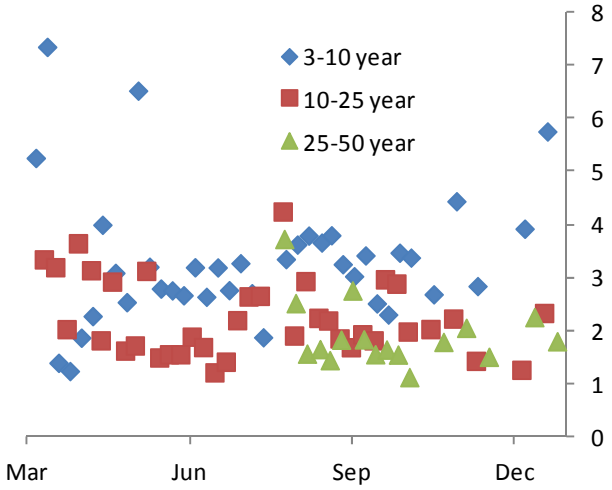


Chart 10: Bid-ask spreads for each gilt across all auctions

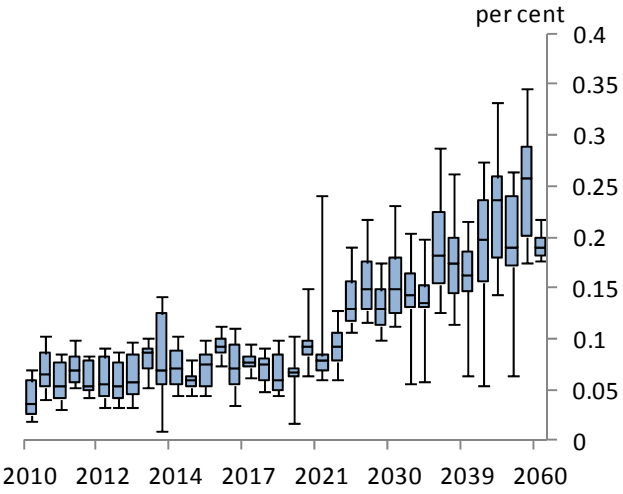


Chart 11: The range of bid-ask spreads at each auction

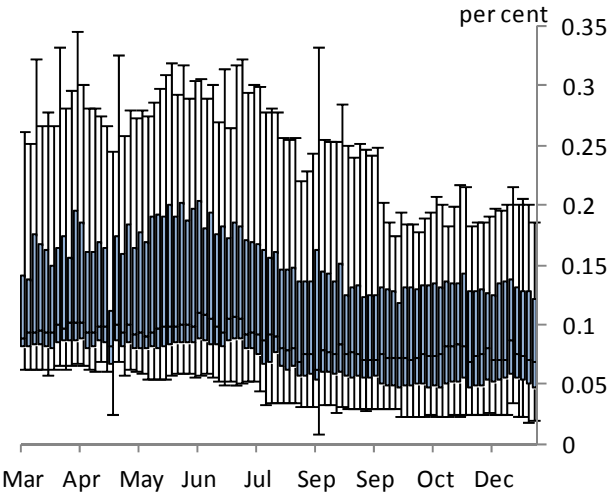
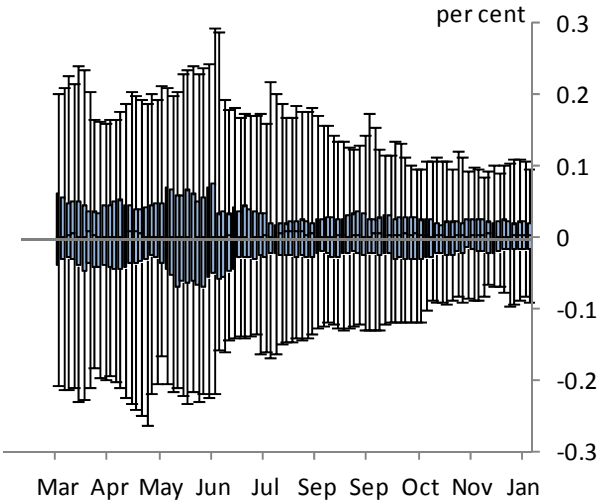


Chart 12: Gilt fitting errors



Source: Data for Charts 10 and 11 are from Tradeweb.

Results

Table 9 shows the results of including these additional seven explanatory variables in the regression of the change in yields on the day of the auction. For those gilts eligible to be purchased in the auction, the most significant factor is the 'auction offer dispersion' – the dispersion across all the accepted offers within the auction. And this was also significant for those gilts not eligible for the auction. As discussed in Section 2, this variable is likely to have reflected, in part, the degree of similarity between the gilts in the auction. For those auctions where there was a high degree of similarity, the offers may be quite similar and hence the auction offer dispersion low. But it is likely that changes in this variable over time also reflect changes in uncertainty, as in Sundaresan (1994). Market makers are unlikely to have been certain about the fall in yields required given the large change in the supply of gilts generated by the Bank's purchases. And a larger degree of uncertainty is likely to be reflected in a wider range of offers in the auction. The negative coefficient on 'auction offer dispersion' means that yields fell more on average following those auctions with a large dispersion. As shown in Section 2, the degree of auction offer dispersion was high in the initial stages of the QE programme and then declined over time, across all the purchase ranges. At the same time, in subsample analysis (not shown), we find that the coefficient on this variable was broadly unchanged over time. This could suggest that high initial uncertainty led to a smaller fall in yields on announcement than was actually necessary to clear the auctions. This was then corrected after each auction as market participants learnt about the realised price elasticity of gilts and their uncertainty declined.

For ineligible gilts, the coefficients on the distribution of purchases were also significant, suggesting that the proximity of purchases in the auction mattered for the impact on their yields. This is also true for eligible gilts in the 10-25 year maturity range when the sample is restricted to the March to July 2009 period, though the size of the effect is around half of that from the regressions excluding auction information. These results are consistent with the presence of local supply effects in the earlier period, but the substitutability between gilts appears to have improved over time, such that in the second half of the sample all gilt purchases had similar effects on yields. For ineligible gilts, the coefficient on the 'bid-offer spread' was also significant: the positive coefficient indicating that less liquid gilts had smaller falls in yields over the day. That would be consistent with less liquid gilts being less substitutable for those in the auction purchase range and hence less likely to mirror the fall in yields.

When we rerun these regressions split into maturity ranges (not shown), we find that for ineligible gilts, the impact on yields from the auction results is increasing in the duration of the subsample with the largest coefficients observed for 25-50 year gilts. This again suggests that longer-duration gilts were more sensitive to an overall reduction in gilt supply.

Overall these results demonstrate a significant impact on gilt yields related to information revealed during the auction process and that the size of those effects related to the duration of the gilt (duration risk effects) and the substitutability for those gilts being purchased (local supply effects).

Table 9: QE purchase effects on gilt yields with liquidity and uncertainty variables

Auction day yield change	Eligible	Ineligible
Own purchases	-0.24	
0-2y purchases	-0.42	-0.61**
2-6y purchases	-0.13	-0.66***
6-14y purchases	-0.19	-0.56***
Clearing spread	-0.1	
Gilt offer dispersion	0.0067	
Auction offer dispersion	-2.9***	-1.1***
Cover ratio	-0.003	0.003***
Fitting error	-0.19**	0.01
Total already purchased	-0.029	-0.008
Bid-offer spread	0.025	0.18***
Number of observations	557	2436
R^2	0.07	0.04

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

As before, we can split the yield change over the day of the auction into: (i) the yield change before the auction; and (ii) the yield change following the auction. For the period leading up to the auction (close of business the previous day until 2.45 pm on the day of the auction), we regress the yield change on the same set of variables, but using only values that were known before the auction. So in this case, our regressors include the purchase amounts in the previous auction (of the same purchase range) and the three liquidity measures: 'fitting error', 'total already purchased' and 'bid-offer spread'. Table 10 shows the results of this regression.[24]

For the yields of eligible gilts, one of the most important statistically significant factors appears to be liquidity, with the yields of less liquid gilts (as measured by the bid-offer spread) falling by more in the run up to the auction. That could be consistent with the auctions temporarily reducing illiquidity premia, which will have a larger impact on less liquid gilts. The other significant factor is the size of the Bank's existing holdings of the gilt ('total already purchased'), which has a positive sign, perhaps reflecting an expectation that the Bank would buy less of those gilts where its holdings were already large.

For ineligible gilts, the gilt yield change leading up to the auction was also larger for less liquid gilts, though the magnitude of the effect was somewhat smaller than for eligible gilts. In contrast to the results for eligible gilts, how close purchases of gilts were in the previous auction of that maturity range was important. As mentioned above, it may be that these variables just act as a proxy for how close the ineligible gilt is to the auction purchase range, with a large impact on the prices of nearby gilts as a result. The other significant factor was again the size of the Bank's existing holdings of the particular gilt.

Table 11 reports the results of regressing the yield changes following the auction (from 2.45pm until close of business) on both the liquidity measures and the auction results (as in Table 9).

[24] Previous auction result variables are not statistically significant if they are also included in this regression.

The similar absolute size but opposite sign of the coefficients on the bid-offer spread and the amount already purchased suggests that the yield fall prior to the auction due to the liquidity of the gilt is broadly unwound. But, as reported above, the auction information variables also have significant effects on yields that are not unwound. Thus, the results suggest that any temporary intraday auction effect on yields was mainly related to liquidity and not to auction information.

Table 10: QE purchase effects on gilt yields pre-auction

Pre-auction intraday yield change	Eligible	Ineligible
Previous own purchase	-0.05	
Previous 0-2y purchase	-0.44*	-0.62**
Previous 2-6y purchase	-0.08	-0.61***
Previous 6-14y purchase	-0.28	-0.25***
Fitting error	0.016	0.003
Total already purchased	0.036**	0.022**
Bid-offer spread	-0.24**	-0.10**
Number of observations	643	2436
R^2	0.01	0.03

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

Table 11: QE purchase effects on gilt yields post-auction

Post-auction intraday yield change	Eligible	Ineligible
Own purchases	-0.1	
0-2y purchases	0.34*	0.28*
2-6y purchases	0.19	0.07
6-14y purchases	-0.09	-0.006
Clearing spread	0.91***	
Gilt offer dispersion	-0.070**	
Auction offer dispersion	-1.3***	-1.1***
Cover ratio	0.012***	0.008***
Fitting error	-0.16***	0.0078
Total already purchased	-0.038***	-0.019***
Bid-offer spread	0.19***	0.23***
Number of observations	557	2436
R^2	0.31	0.14

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

If the effects captured in these regressions really reflect learning by market participants about the overall required change in yields from the purchases, as well as just temporary effects, then we would expect them to be persistent. Table 12 shows the results of repeating the regressions in Table 9 for the change in gilt yields over the two days following the auction. This shows considerable persistence in the effects, with statistically significant negative coefficients on

auction information. When we split the sample period as before (not shown), the coefficients on auction information remain broadly similar throughout, whilst the impact of the distribution of purchases still appears to have declined over time. The negative and significant coefficient on the total already purchased also suggests that the persistent fall in yields was greater where the Bank already held a higher proportion of the bonds. One puzzling difference between the two sets of regressions is that the cover ratio changes to having a negative rather than positive effect on yields, suggesting that well-covered auctions were associated with larger falls in yields over time.

Table 12: Two-day QE purchase effects on gilt yields with liquidity and uncertainty variables

Two-day yield change	Eligible	Ineligible
Own purchases	-0.15	
0-2y purchases	-0.58	-0.35
2-6y purchases	-0.66*	-0.88***
6-14y purchases	-0.95	-0.78***
Clearing spread	0.26	
Gilt offer dispersion	-0.098	
Auction offer dispersion	-2.4***	-0.74***
Cover ratio	-0.021***	-0.014***
Fitting error	-0.25**	-0.0047
Total already purchased	-0.091***	-0.054***
Bid-offer spread	0.16	0.47***
Number of observations	557	2436
R^2	0.03	0.02

Notes: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

5.3 Conclusion

Overall, the data suggest that, on average, a small temporary premium built up ahead of the auctions and then broadly unwound before the close of business on the same day. There is evidence that the size of the initial impact on yields was related to the pattern of the Bank's gilt purchases, at least during the first half of the period. Moreover, the size of the responses was related to the duration of the gilt and how substitutable it was for those gilts being purchased, providing evidence of both local supply and duration risk effects. But, in addition to that, the results of the auction appear to have had a more persistent impact on prices as market participants learnt about other participants' behaviour and the appropriate market price given the overall change in supply.

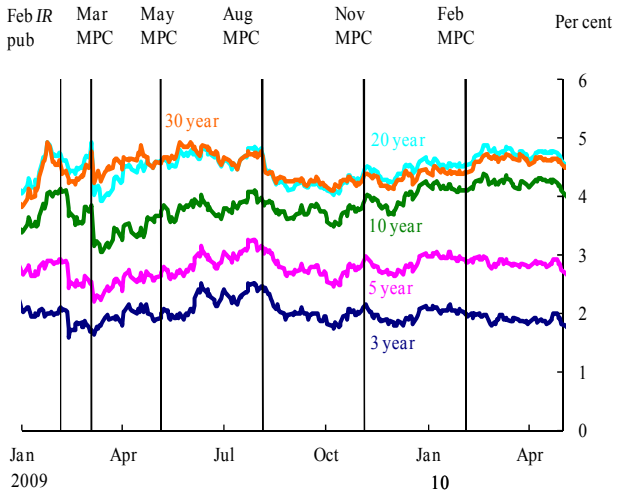
6 Longer-term yield effects

The results from Section 5 suggest that, while liquidity appeared to be the main driver of temporary flow effects around the auction dates, there were also more persistent effects on yields associated with auction information and the amounts purchased. This may suggest that the event study analysis of announcement effects understates the true impact on gilt yields of the change in gilt stocks resulting from QE. However, it is not clear precisely how quickly the

impact on gilt yields may diminish, perhaps as a result of expected future sales of gilts by the Bank, or the impact of gilts maturing.

Chart 13 shows that gilt yields at a number of different horizons showed little net change over the 2009-10 period. But the fact that yields showed little net change need not imply that QE was ineffective.[25] Obviously there were other potentially important variables affecting yields during the period of QE purchases. One oft-cited factor is the perceived riskiness of the UK Government's fiscal position, which may have put upward pressure on gilt yields over this period, making it hard to estimate the persistence of the effect from QE purchases. Chart 14 shows that the spreads on UK sovereign credit default swaps (CDS) - one commonly used indicator of default risk[26] - widened following the collapse of Lehman Brothers in September 2008, as the UK Government took some of the risk from RBS and Lloyds Banking Group onto its balance sheet. Following the improvement in banking sector balance sheets during the middle of 2009, CDS spreads narrowed. But CDS spreads subsequently widened, as concerns increased about the size of the UK Government's deficit. These concerns will have affected UK gilt yields at the same time as the QE purchases were being made.

Chart 13: Gilt yields[(a)]



Source: Bloomberg.
(a) Estimated zero-coupon rates.

Chart 14: UK 10-year sovereign CDS rates

Source: Bloomberg.

6.1 Time-series regressions

In order to try and quantify the respective impact of fiscal concerns, the changing macroeconomic outlook and QE purchases, we run panel regressions on daily yield-to-maturities of all gilts with 5 years or more to maturity over the period January 2009 – April 2010.[27] More precisely, we estimate the following specification:

[25] Simple cross-sectional regressions of cumulative price changes (over the whole purchase period) on cumulative purchase amounts suggest, perhaps unsurprisingly, that the more persistent impact of QE purchases was close to zero. This is the case whether or not we account for the potential endogeneity of the QE purchases by instrumenting, although given the non-discretionary way the purchases were conducted (see Section 2) we think endogeneity is less likely to be important than in the US case (see D'Amico and King (2010)).
[26] Although relatively illiquid compared to the government bond market, there was a large increase in the volumes traded in the CDS market after the collapse of Lehman Brothers, which has led to the increased use of CDS spreads as a measure of market sentiment (*Financial Times*, (2009b)).
[27] This unbalanced panel of gilt yields rejects at the 99% level the null hypothesis of the Fisher test for unit roots, both based on Dickey-Fuller tests and based on Phillips-Perron tests.

$$Y_t^i = \alpha_i + \beta QE_t + \sum_{j=0}^{3} \gamma_{i,j}\, CumQ_t^{i,j} + \sum_{j=0}^{1} \delta_j\, Fiscal_t^j + \; OIS_t + \varepsilon_t^i \qquad (4)$$

where

- Y_t^i denotes the yield to maturity on gilt i (in per cent),
- QE_t is the expected amount of total QE purchases (measured by the mean of the Reuters survey of economists linearly interpolated over time, in £ billions),
- $CumQ_t^{i,j}$ denotes cumulative purchases of individual and nearby gilts (measured by the cumulative size of each of the purchase variables in the regressions of yield changes around auctions reported in Section 5),
- $Fiscal_t^j$ denotes our proxies for the fiscal position: (i) the expected total size of UK public sector net borrowing (PSNB) in the period 2008-13 (the mean of the quarterly HMT survey of economists linearly interpolated over time, in £ billions); and (ii) the level of 10-year UK sovereign CDS spreads (in per cent),
- OIS_t denotes the three-year spot OIS rate (in per cent), to control for the expected path of Bank Rate (and the risk around it) in the near-term.

6.2 Results

The results from this regression are shown in column (1) of Table 13.[28] In column (2), we also estimate an alternative specification where, in order to account for the potentially greater temporary impact of QE during the period when gilt purchases were being made, we include five dummy variables indicating the period when each gilt was included in one of the five auction types.

The estimated coefficients in column (1) of Table 13 suggest that the expectation of £200 billion of purchases reduced yields on average over the period by around 35 basis points. But allowing for the effect of having made the purchases reduces this negative impact to around 10 basis points.[29] Including gilt-specific dummy variables for the periods in which they were eligible to be bought, as reported in column (2), indicates that the temporary effect during the purchase period was large at around 50 basis points. That could suggest that the more persistent impact from QE on yields was actually positive.

A long-term positive impact from QE on yields is not inconsistent with what one may expect from the policy. Successful QE is likely to be associated with expectations of higher future demand and inflation, both of which are likely to put upward pressure on gilt yields. To allow for this effect, column (3) in Table 13 reports the results from including two additional variables in the panel data regression:

- Expected GDP growth on average over the period 2010-12 (the mean response of the quarterly HMT survey of economists linearly interpolated over time, in £ billions)
- Expected CPI inflation on average over the period 2010-12 (the mean response of the quarterly HMT survey of economists linearly interpolated over time, in £ billions)

[28] Cluster-robust standard errors are reported to account for potential serial correlation.

[29] (QE purchased)*(coefficient on expectations)-((average 0-2y purchased)*(coefficient on 0-2y purchases)+(average own purchase)*(coefficient on own purchases)) = 200*0.0018 – (0.25*1.00+0.05*0.05) = 11bp.

Under this specification, the coefficients associated with QE expectations and purchases suggest there was a much larger persistent negative impact on gilt yields from QE of around 120 basis points with an additional temporary effect during the purchase period of around 30 basis points.[30] These effects are offset by changes in both expectations of the United Kingdom's fiscal position and expectations of inflation and GDP. This estimate of the impact of QE on gilt yields is larger than that estimated from just the announcement effects in Section 4 and so is consistent with the results from Section 5 that the impact on yields increased when the actual purchases were made.

6.3 Conclusion

These regressions are reduced form, so we may not want to place a large amount of weight on the precise parameter estimates. But the results do seem consistent with QE having a persistent effect on gilt yields. This finding would be consistent with the stock-based portfolio balance approach that we used to explain the effects of QE in Section 3.

[30] (QE purchased)*(coefficient on expectations)-((average 0-2y purchased)*(coefficient on 0-2y purchases)+(average own purchase)*(coefficient on own purchases)) = 200*0.0062 – (0.25*0.31-0.05*0.02) = 116bp. Average of time period dummies = 34bp.

Table 13: Panel data regression of the level of gilt yield-to-maturities: Jan 2009 – Apr 2010

Gilt yields	(1)	(2)	(3)
Reuters QE expectations	-0.0018***	0.0004	-0.0062***
UK government borrowing expectations	0.0012**	0.0009	0.0090***
UK sovereign CDS	0.0021***	0.0022***	-0.0002
3-year OIS rate	0.01	-0.01	0.25***
Own purchases	0.06	0.48**	0.31**
0-2y purchases	1.00***	1.10***	0.25
2-6y purchases	0.10	0.06	-0.02
6-14y purchases	0.01	0.01	-0.02
Bid-ask spread	2.4***	2.1***	1.6***
May-July 5-10y auction dummy		-0.53***	-0.40***
May-July 10-25y auction dummy		-0.30**	-0.21**
Aug-Jan 3-10y auction dummy		-0.50***	-0.45***
Aug-Jan 10-25y auction dummy		-0.41	-0.36**
Aug-Jan 25-50y auction dummy		-0.24**	-0.29***
UK GDP growth expectations			0.87**
UK CPI inflation expectations			1.80***
Number of observations	7589	7589	7589
R^2	0.06	0.23	0.28

Note: Fixed effects are not reported. ***/**/* denotes statistical significance at the 1%/5%/10% level.

7 Summary and conclusion

In this paper we examined the impact of the Bank of England's QE purchases on the UK government bond market during March 2009 to January 2010, using high-frequency disaggregated data on individual gilts. Analysis of the high-frequency market reactions to individual announcements on QE suggested that the initial impact from the announcements took time to be fully priced in and that the cumulative initial impact on yields varied significantly across the term structure, with the largest impact up to 120 basis points at the 15 to 20-year maturity. We also found evidence of both local supply and duration risk effects in the pattern of the yield reactions across the term structure.

Analysis of the Bank of England's reverse auctions suggested that they led to further average reductions in eligible and ineligible gilt yields of 2.5 basis points and 1.5 basis points respectively ahead of each auction. These effects were not always reversed before close of business on the same day, with more persistent effects found to be associated with a large degree

of price dispersion of the accepted offers, an indicator of price uncertainty. We speculated that these persistent effects partly reflected learning by market participants. In addition, we found there was evidence that the importance of the overall effects of the auctions on gilt yields diminished over time, as liquidity and market functioning improved and market participants learnt about the operation of the Bank's asset purchase programme.

Putting our results together suggests that the peak gilt market response to the Bank's QE policy may not have occurred until the auction purchases began and the market learnt about the effects of the policy. Overall our results imply that the Bank's QE asset purchases had a significant and persistent impact on gilt yields. Our paper also provides evidence of local supply and duration risk effects consistent with imperfect substitution, which has implications beyond the financial crisis for how we think about price determination in the gilt market.

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