The Financial Market Impact of Quantitative Easing in the United Kingdom*

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This paper investigates the impact of the Bank of England's quantitative easing policy on UK asset prices. Based on analysis of the reaction of financial market prices and model-based estimates, we find that asset purchases financed by the issuance of central bank reserves—which by February 2010 totalled £200 billion—may have depressed medium to long-term government bond yields by about 100 basis points, with the largest part of the impact coming through a portfolio balance effect. The wider impact on other asset prices is more difficult to disentangle from other influences: the initial impact was muted, but the overall effects were potentially much larger, though subject to considerable uncertainty.

JEL Codes: E43, E44, E52, E58.

1. Introduction

The intensification of the global financial crisis that followed the collapse of Lehman Brothers in September 2008 led to governments and central banks around the world introducing a variety

 The views expressed in this paper are those of the authors and not necessarily those of the Bank of England. We would particularly like to thank Chris Kubelec and Jens Larsen for their help and advice on this paper. We are also grateful to Mark Astley, James Bell, Alan Castle, Martin Daines, Spencer Dale, Iain de Weymarn, Paul Fisher, Joseph Gagnon, Rodrigo Guimaraes, George Kapetanios, David Miles, Joe Noss, Chris Peacock, Adam Posen, Simon Price, Jon Relleen, Ryland Thomas, Kyriaki Voutsinou, Carl Walsh, Chris Yeates, and three anonymous referees for useful comments. Any remaining errors are of course the responsibility of the authors. The authors can be contacted at mike.joyce@bankofengland.co.uk, ana.lasaosa@bankofengland.co.uk, ibrahim.stevens@bankofengland.co.uk, and matthew.tong@bankofengland.co.uk.

of measures aimed at stabilizing financial conditions and supporting aggregate demand (see, e.g., Klyuev, de Imus, and Srinivasan 2009 for a review).

In the United Kingdom, a large monetary policy easing was accomplished using both conventional and unconventional measures.[1] The Bank of England's Monetary Policy Committee (MPC) cut the Bank Rate, the United Kingdom's policy rate, in a sequence of steps from 5 percent at the start of October 2008 to 0.5 percent in March 2009. But in reducing policy rates to their effective floor, the MPC also announced that, in view of the substantial downside risks to achieving the 2 percent CPI inflation target in the medium term, it would ease monetary conditions further through a program of asset purchases financed by the issuance of central bank reserves.

This policy of asset purchases has come to be known as quantitative easing (QE).[2] In general terms, QE is normally defined as a policy that expands the central bank's balance sheet, in order to increase the level of central bank money (in particular, bank reserves) in the economy (see Bernanke and Reinhart 2004). This is sometimes contrasted with a policy of changing the composition of the assets on the central bank's balance sheet (often referred to as credit easing); for example, by shifting between short and longer-maturity government bonds or by shifting into riskier private assets, such as corporate bonds or equities. The Bank of England's policy has elements of both, though the main emphasis was on expanding the balance sheet.[3] The MPC decided that it would purchase both private- and public-sector assets using central bank reserves, though the majority of purchases would be of UK government securities

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[1] Though not identical, there are many similarities between the policies implemented by the main central banks during the financial crisis (see Miles 2010). D'Amico and King (2010) and Gagnon et al. (2011) review the impact of large-scale asset purchases by the U.S. Federal Reserve. Neely (2010) looks at the wider international effects of the Federal Reserve's asset purchases.

[2] The terminology was first used to describe the Bank of Japan's policy during 2001 to 2006 (see, e.g., Ugai 2007 and Shiratsuka 2009).

[3] The asset purchases were conducted through a separate legal entity, the Bank of England Asset Purchase Facility Fund, a limited company. The Fund and the Bank are fully indemnified by the Treasury from any losses arising out of or in connection with the asset purchase program. For a discussion of how asset purchases affected the Bank of England's accounts, see Bean (2009).

(gilts).[4] By purchasing financial assets from the private sector, the aim was to boost the amount of money in the economy, which would increase nominal spending and thereby ensure that inflation was on track to meet the CPI inflation target over the medium term.

By February 2010, the Bank of England had completed £200 billion of asset purchases as part of its QE policy, overwhelmingly comprising conventional gilts. Alongside separate liquidity support to the banking sector, these purchases expanded the Bank's balance sheet as a proportion of nominal GDP to three times its level before the onset of the crisis in the summer of 2007, as large as at any point in the past two centuries (see Cross, Fisher, and Weeken 2010). The Bank's gilt purchases represented 29 percent of the free float of gilts (the amount of non-official holdings of gilts) and were equivalent to around 14 percent of nominal GDP.

This paper examines the impact of these extraordinary measures on financial markets. Given their overwhelming importance, we will focus on the effects of the Bank's gilt purchases and will not directly discuss the impact of the other purchase facilities set up by the Bank. Our aim is to review how QE has affected gilt markets and how it has fed through more widely into other financial asset prices, like equities and corporate debt.

Since the motivation for the United Kingdom's QE purchases was to increase nominal spending on goods and services, in order to meet the MPC's inflation target, it might not be obvious why we should be concerned with the financial market impact per se. But judging the impact of QE in stimulating the macroeconomy is difficult, as the transmission mechanism may be subject to long lags, and it is hard to measure the specific contribution of the MPC's asset purchases, given the influence of other policy measures and other economic developments in the United Kingdom and internationally. The place where we might have expected to see the clearest direct impact of QE is in the reaction of financial markets. This in turn may provide the most timely and clearest read on the effectiveness of the policy and how it might be feeding through to the rest of the economy.

[4]The smaller purchases of corporate bonds and commercial paper were aimed at improving the functioning of those markets and therefore improving access to credit for firms (see Fisher 2010).

The rest of the paper is structured as follows. In section 2, we discuss the main channels through which QE asset purchases may affect financial markets and how we might attempt to estimate the relative importance of the various channels. Section 3 describes the evolution of the MPC's QE-related asset purchase program and how it has been implemented. In sections 4 and 5, we examine the immediate reaction of asset prices to the Bank's QE announcements, and allocate it into separate channels, using event-study analysis and survey data. Overall, our analysis suggests that the dominant effect has been through a portfolio balance channel. To provide a benchmark for the impact that might have been expected through this channel, section 6 uses two portfolio balance models estimated on pre-crisis data to quantify the impact on expected asset returns of changes in asset quantities. These results are broadly consistent with the observed initial reaction of asset prices to QE, although there is considerable uncertainty around the estimated effects, especially for equities. Section 7 draws overall conclusions.

2. QE and Asset Prices

By injecting money into the economy, in return for other assets, a central bank can increase the liquidity of private-sector balance sheets. As discussed in Benford et al. (2009), there are a number of ways through which this greater liquidity can have an impact on the economy. First, purchases of assets financed by central bank money should push up the prices of assets. This is the impact analyzed in this paper. If asset prices are higher, this reduces the cost of borrowing, encouraging higher consumption and investment spending. Higher asset prices also increase the wealth of asset holders, which should boost their spending. The other ways in which QE may potentially work—mainly, through expectations, by demonstrating that the MPC will do whatever it takes to meet the inflation target, and through influencing banks' lending ability—fall outside the scope of this paper.

2.1 Asset Price Channels

In our framework, there are three main channels through which QE might affect asset prices: macro/policy news, portfolio balance, and liquidity premia.

The *macro/policy news channel* refers to anything economic agents might learn from the Bank of England's QE announcements about the underlying state of the economy and the MPC's reaction function. This channel captures news about expected future policy rates—often referred to as the "signaling channel"[5]—but, if we define it more broadly to include perceptions of the risks around the path of future short-term interest rates, it should also include revisions to term premia. As well as affecting gilt yields, this channel will feed through into other asset prices to the extent that the relevant discount rates are affected. In principle, the overall sign of these effects on yields/prices might be either positive or negative. While QE might signal lower policy rates in the short term, it could also signal higher inflation in the future, leaving the impact on nominal gilt yields ambiguous.

The *portfolio balance channel* reflects the direct impact on asset prices of investors rebalancing their portfolios in response to the Bank of England's QE-related asset purchases. Tobin (1961, 1963, and 1969) and subsequently Brunner and Meltzer (1973) and Friedman (1978), amongst others, showed that if assets are not perfect substitutes, then a change in the quantity of a specific asset will lead, ceteris paribus, to a change in its relative expected rate of return. Thus imperfect substitutability provides a mechanism for QE-related asset purchases by the Bank to affect asset prices by inducing sellers to rebalance their asset portfolios. Provided long-term gilts and money are imperfect substitutes, QE-related gilt purchases would be expected to reduce bond yields and lead to investors increasing their demand for other long-term assets. The impact through this channel may occur both on announcement and over time as investors are able to adjust their portfolios. Since this channel depends on perceptions of the path of outstanding *stocks* of gilts and money, we would expect it to be persistent.

In conventional New Keynesian models, portfolio balance effects are not present and QE can only work through a signaling channel (see, e.g., Eggertsson and Woodford 2003). Asset purchases on their own do not change behavior because the assumptions typically

[5]Most of the related literature on QE refers to the signaling and portfolio balance channels. See, for example, Clouse et al. (2003), Bernanke, Reinhart, and Sack (2004), Ugai (2007), and Borio and Disyatat (2009).

made imply that the distinction between government and private asset holdings is unimportant, in a way reminiscent of Ricardian equivalence. In these models, QE can be effective only if it changes expectations regarding the path of future policy rates and/or inflation. This naturally leads to the conclusion that committing to a path for future interest rates may be more effective than undertaking asset purchases. But, in a model with financial frictions (e.g., credit constraints or distortionary taxes) or incomplete markets, and with imperfect substitutability between different assets, QE can also affect asset prices by changing the relative supplies of different assets.

The view that imperfect asset substitutability can be important is reflected in an emerging theoretical literature that builds microfoundations for these effects from the earlier contributions of Tobin and others. For example, Andrés, López-Salido, and Nelson (2004) introduce an adjustment to household preferences in a New Keynesian model to allow for imperfect asset substitutability between holdings of long-term bonds and money for certain households. Their framework can be thought of as a way of introducing "preferred habitat" investors (Modigliani and Sutch 1966) into a dynamic stochastic general equilibrium setting. More recently, using a partial equilibrium approach, Vayanos and Vila (2009) propose a theoretical model of preferred habitat, in which bond prices are determined through the activities of risk-averse arbitrageurs and preferred-habitat investors. In this setup, they demonstrate that shocks to bond supply are a determinant of bond prices, thus providing another rationale for expecting QE to have an effect on long-term bond yields.

In addition to the portfolio balance effect, the presence of the central bank in the market as a significant buyer of assets may improve market functioning and thereby reduce premia for illiquidity. This *liquidity premia channel* effect reflects the fact that the central bank's purchases may make it less costly for investors to sell assets when required. In normal times, markets may be deep and liquid, but in stressed conditions, premia for illiquidity could be significant. Since this channel depends on the *flow* of purchases for its effect, we would expect it to be temporary and limited to the duration of the asset purchase program.

How does the MPC's asset purchase program fit into this description? At a general level, the QE program seemed firmly based on a view that there would be significant portfolio rebalancing. The MPC's asset purchase program was directed toward large-scale purchases of conventional gilts: the impact was expected to be seen in gilt markets, but also across a broader range of asset prices and in real activity and inflation. The MPC did not explicitly use these purchases to signal future intentions, emphasizing instead its commitment to meeting the inflation target through the usual channels of monetary policy communications—including the MPC minutes and the quarterly Inflation Report. Nor were its actions focused on improving the functioning of gilt markets, where liquidity premia, even in stressed times, were considered to be small.[6]

Given the unusual character of the intervention, and the absence of a clear consensus on the exact impact of asset purchases generally, our approach is based on the notion that financial markets are incomplete or imperfect, while being agnostic on the exact source and size of any market frictions. That said, we do not want to rule out significant signaling or expectational effects, so we also investigate this channel in our empirical approach.

It is important to note here that though these channels are broadly defined compared with much of the literature on the topic, they do not capture the fact that asset purchases—with other macroeconomic policies—may have substantially changed the distribution of future macroeconomic outcomes, and thereby affected risk premia more broadly (e.g., equity risk premia). Dale (2010) discusses this in more detail.

2.2 Measuring the Asset Price Channels

In order to quantify the impact of QE purchases, we use several approaches: event-study methods are discussed in sections 4 and 5 and time-series econometric methods in section 6.

In attempting to quantify the role of the various channels in affecting gilt yields, we rely crucially on interest rates from overnight index swap (OIS) contracts. An OIS is a contract that involves the exchange of a predefined fixed interest rate (the OIS rate) with one linked to a compounded overnight interbank interest rate that has

[6]The liquidity channel effect was nevertheless thought important for purchases of private-sector assets.

prevailed over the life of the contract. Since they settle on overnight interest rates and are collateralized, OIS rates should incorporate minimal credit risk. The OIS market has built up rapidly in recent years, and, at least at short maturities, these contracts are actively traded and should therefore also incorporate little liquidity risk.[7] On the assumption that OIS rates provide an accurate measure of default risk-free rates that are, as a derivative contract, less affected by supply constraints in the gilt market, movements in OIS rates should provide a measure of macro/policy news. Movements in the spread between gilt yields and OIS rates then represent the combined effect of the portfolio balance and liquidity channels.

To clarify our approach, it may help to start with the following well-known expression, which decomposes bond yields into expected future short-term interest rates and a term premium:

$$y(gilt)_t^n = (1/n)\sum_{i=0}^{n-1} E_t r_{t+i} + TP(gilt)_t^n, \tag{1}$$

where $y(gilt)_t^n$ is the n-period maturity yield on a government bond, r_{t+i} denotes the one-period (risk-free) short-term interest rate, and $TP(gilt)_t^n$ denotes the n-period term premium. In our framework, the term premium on gilts comprises two elements: $TP1(gilt)_t^n$, an instrument-specific effect that captures gilt-specific credit/liquidity premia and any effects from demand/supply imbalances, and $TP2(gilt)_t^n$, a term premium element that reflects uncertainty about future short-term interest rates:

$$TP(gilt)_t^n = TP1(gilt)_t^n + TP2(gilt)_t^n. \tag{2}$$

If we assume that credit risk premia on gilts are negligible, then movements in gilt-specific premia, $TP1(gilt)_t^n$, will reflect either changes in liquidity premia or demand/supply effects from QE that come through the portfolio balance channel. We examined separate evidence on market functioning (e.g., bid-ask spreads) to enable us to identify the role of the liquidity premia channel, but the importance of this channel appears to be small in the context of gilts,

[7] At longer maturities this may be less true, and it is possible that OIS rates may incorporate liquidity premia. See the discussion below.

so we place more emphasis on the relative importance of portfolio balance effects in driving gilt-specific premia around QE announcements.[8]

It is possible to write down a similar breakdown for yields implied by OIS contracts:

$$y(OIS)_t^n = (1/n)\sum_{i=0}^{n-1} E_t r_{t+i} + TP(OIS)_t^n, \tag{3}$$

where $y(OIS)_t^n$ is the n-period maturity OIS rate, r_{t+i} is the one-period short (risk-free) rate, and $TP(OIS)_t^n$ denotes the OIS n-period term premium. Again, in principle, the term premium implied by OIS rates can be broken down into two elements: $TP1(OIS)_t^n$, an instrument-specific premium, and $TP2(OIS)_t^n$, a conventional term premium.

$$TP(OIS)_t^n = TP1(OIS)_t^n + TP2(OIS)_t^n \tag{4}$$

The working assumption in our analysis is that the first $TP1(OIS)_t^n$ element is negligible, so that movements in OIS term premia reflect fundamentals to do with interest rate uncertainty rather than liquidity or credit risk premia or effects from demand/supply. A corollary of this is that the component of the gilt-yield term premium reflecting interest rate uncertainty (i.e., $TP2(gilt)_t^n$) will be the same as in the corresponding maturity-matched OIS rate:

$$TP(OIS)_t^n = TP2(OIS)_t^n = TP2(gilt)_t^n.$$

It follows that

$$\begin{aligned} y(gilt)_t^n - y(OIS)_t^n &= TP1(gilt)_t^n + TP2(gilt)_t^n - TP(OIS)_t^n \\ &= TP1(gilt)_t^n. \end{aligned} \tag{5}$$

Thus changes in the gilt-specific premia element, and the effects of the portfolio balance channel, should be proxied by changes in the spread between gilt yields and OIS rates. But to the extent

[8]See Joyce et al. (2010) for further details.

that OIS rates are driven by some of the same factors influencing gilt-specific premia (e.g., demand/supply imbalances), changes in gilt-OIS spreads will tend to underestimate the effects of portfolio rebalancing.

One implication of our approach is that QE can potentially affect the term premium through both the macro/policy news channel, as we have defined it, and through portfolio rebalancing. As we shall show in later sections, the evidence suggests on balance that the impact on gilt yields has been dominated by a portfolio balance effect, which would suggest that the term premium effect has broadly coincided with the portfolio balance effect.

3. The United Kingdom's Unconventional Policy Measures

In this section we describe the unconventional monetary policy measures that the Bank of England took in response to the financial crisis.

3.1 Initial Responses

The Bank's initial response to the financial crisis during 2007–08 included a range of measures aimed at providing liquidity insurance to the markets (see, e.g., Cross, Fisher, and Weeken 2010 for more details). The Bank's lending operations were extended beyond the amounts needed for banks to meet their pre-arranged reserves targets, which were themselves increased. The Bank conducted larger amounts of three-month repo operations and extended the collateral accepted. In April 2008, after the collapse of Bear Stearns, the Bank introduced a Special Liquidity Scheme (SLS) that allowed banks and building societies to swap high-quality, but temporarily illiquid, mortgage-backed and other securities for UK Treasury bills. Along with other central banks, in the wake of the collapse of Lehman Brothers in September 2008, the Bank established a swap facility with the Federal Reserve, providing an additional means whereby banks could borrow U.S. dollars. And, in October 2008, a Discount Window Facility was launched as a permanent liquidity insurance facility.

All these operations were aimed at providing liquidity support to the markets rather than changing the implementation of monetary policy. Towards the end of 2008, some of the extra liquidity introduced by these measures started to be drained with one-week Bank of England bills. The Bank's means of implementing monetary policy were largely unchanged until the start of the QE policy in March 2009.

3.2 The APF and QE

The Bank of England Asset Purchase Facility Fund was set up on January 30, 2009 as a subsidiary of the Bank of England. The Fund is fully indemnified by the Treasury from any losses arising out of or in connection with the Asset Purchase Facility (APF), ensuring that the Bank will not incur any losses arising from the asset purchase program (for further discussion, see Bean 2009). The APF was initially authorized to purchase up to £50 billion of private-sector assets—corporate bonds and commercial paper—financed by the issuance of Treasury bills and Debt Management Office (DMO) cash management operations, in order to improve liquidity in credit markets that were not functioning normally. The first purchases of commercial paper began on February 13, 2009.

The APF's remit was subsequently expanded to allow it to be used as a monetary policy tool ahead of the March 2009 MPC meeting. The Committee was given the option to finance purchases under the APF by issuing central bank reserves, and the range of eligible assets was expanded to include gilts. After the financial crisis worsened following the collapse of Lehman Brothers in September 2008, the MPC reduced the Bank Rate in a sequence of steps from 5 percent to 0.5 percent. When the final reduction of the Bank Rate from 1 percent to 0.5 percent was announced on March 5, 2009, the MPC also announced that it would undertake a program of asset purchases financed by the issuance of central bank reserves. The Sterling Monetary Framework was adjusted: among other changes, reserves targets were suspended and all reserves started being remunerated at the Bank Rate.[9]

[9]For more details, see the consolidated notice at www.bankofengland.co.uk/markets/marketnotice090820smf-apf.pdf.

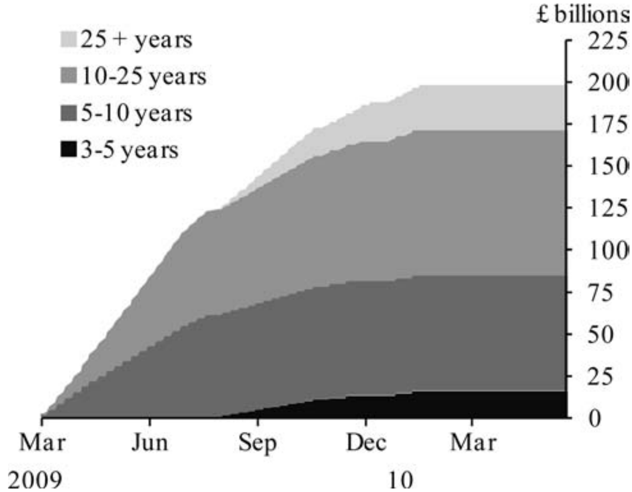
In order to meet the Committee's asset purchase objectives, the Bank announced that it would buy private and public assets, but that it was likely that the majority of overall purchases would be of gilts. The purchases of gilts were initially restricted to conventional gilts with a residual maturity between five and twenty-five years. Further extensions of the program were subsequently announced after the May, August, and November 2009 MPC meetings. After the August 2009 MPC meeting, the maturity range of gilt purchases was extended to three years and above. By February 2010, when the MPC announced that it would pause its program of purchases, the Bank had made £200 billion of asset purchases, of which £198 billion were gilts. Since January 2010, the Bank has been acting both as a buyer and a seller of corporate bonds, in order to improve liquidity in the market. From February 4, 2010, all purchases of corporate bonds and commercial paper have been financed by the issuance of Treasury bills and DMO cash management operations.

3.3 The Gilt Purchase Program

The Bank's gilt purchases were conducted through reverse auctions, whereby counterparties submitted prices at which they offered to sell specific quantities of individual gilts. These were held twice a week from March until August 2009 and three times a week after the August MPC meeting. The first gilt auction was conducted on March 14, 2009. At each auction the Bank accepted the cheapest offers (relative to market prices), up to the total amount to be purchased. The Bank bought widely across all maturities of available bonds (figure 1) but did not hold more than around 70 percent of the free float of any individual gilt. Although the counterparties in the auctions were banks and securities dealers, they could submit bids on behalf of their customers. And the auctions also allowed non-competitive bids to be made by other financial companies, whereby they agreed to sell gilts at the average successful price accepted in the competitive auction.

Since financial institutions may have bought up gilts in anticipation of selling them to the Bank, it is difficult to tell who the ultimate sellers were. But, as reported in Benford et al. (2009), the distribution of total gilt holdings at the end of 2008 suggests that

Figure 1. Cumulative Gilt Purchases by Maturity



Source: Bank of England.

banks held a comparatively small fraction of the total outstanding stock. Purchases of banks' gilts holdings will have shown up only in higher reserve balances at the Bank of England, and not in broad money aggregates (which includes deposits held by households and non-banks with commercial banks), unless the additional reserves led to increased bank lending or further purchases of assets from the non-bank private sector. But, other things equal, purchases from the non-bank private sector will have resulted in higher bank deposits and therefore will have been recorded as additional broad money. So to the extent that the purchases were ultimately from non-banks, we might have expected to see a large initial impact in the broad money data. (This motivates our approach in section 6, where we model the effect of QE as a swap between broad money and gilts.)

Table 1 sets out more details on the timetable of QE announcements. These are the events we will focus on in the next two sections, where we look at the reaction of financial markets to QE news. Although the first announcement of asset purchases was made in March, the publication of the February Inflation Report and the associated press conference on February 11 had given a strong indication that QE asset purchases were likely, which had an impact

Table 1. Key QE Announcement Dates

Announcement	Decision on QE	Other Information
February 11, 2009	The February Inflation Report and the associated press conference gave strong indication that QE asset purchases were likely.	
March 5, 2009	The MPC announced that it would purchase £75 billion of assets over three months financed by central bank reserves, with conventional bonds likely to constitute the majority of purchases. Gilt purchases were to be restricted to bonds with a residual maturity of between five and twenty-five years.	The Bank Rate was reduced from 1 percent to 0.5 percent.
May 7, 2009	The MPC announced that the amount of QE asset purchases would be extended by a further £50 billion to £125 billion.	
August 6, 2009	The MPC announced that the amount of QE asset purchases would be extended to £175 billion and that the buying range would be extended to gilts with a residual maturity greater than three years.	The Bank announced a gilt lending program, which allowed counterparties to borrow gilts from the APF's portfolio in return for a fee and alternative gilts as collateral.
November 5, 2009	The MPC announced that the amount of QE asset purchases would be extended to £200 billion.	
February 4, 2010	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 program and that further purchases would be made should the outlook warrant them.

on asset prices.[10] The next key dates were the further extensions of the program announced after the May, August, and November 2009 MPC meetings. At the August meeting, the Committee voted to raise the stock of assets purchased to £175 billion. Two additional decisions were also taken in August: the maturity range was increased from five to twenty-five years to three years and over, and some of the gilts purchased were made available for on-lending to the market through a gilt lending arrangement with the DMO.[11] The purchase program was further extended to £200 billion in November, maintaining the maturity range of three years and above. Finally, the decision in February 2010 to pause asset purchases, but to continue to monitor the appropriate scale of purchases, might have been expected to have an impact.

4. Gilt Market Reactions

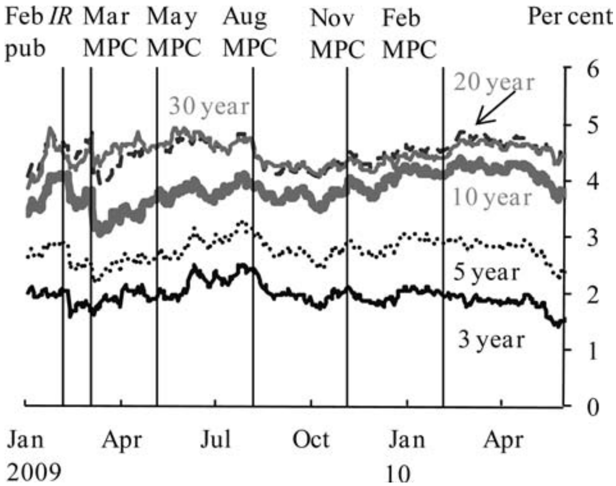
Since gilts made up the overwhelming majority of the Bank of England's asset purchases, it is natural to begin by first assessing the impact of QE on gilt yields.

Figures 2 and 3 show gilt yields and the spread between those yields and corresponding OIS rates at a number of maturities between January 2009 and May 2010. Both gilt yields and gilt-OIS spreads fell after the first announcements of QE in February and March 2009, consistent with a QE impact coming from both the macro/policy news and portfolio balance channels described in section 2. But comparing their levels at the end of May 2010 with where they were before the start of QE in February 2009 suggests little overall change at most maturities. However, net changes over the period are unlikely to provide a good measure of the overall

[10] Opening remarks at the press conference from the Bank of England Governor, Mervyn King, included the following statement: "The projections published by the Committee today imply that further easing in monetary policy may well be required. That is likely to include actions aimed at increasing the supply of money in order to stimulate nominal spending." (See www.bankofengland.co.uk/publications/inflationreport/irspnote110209.pdf). When answering questions from the press, he said 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).

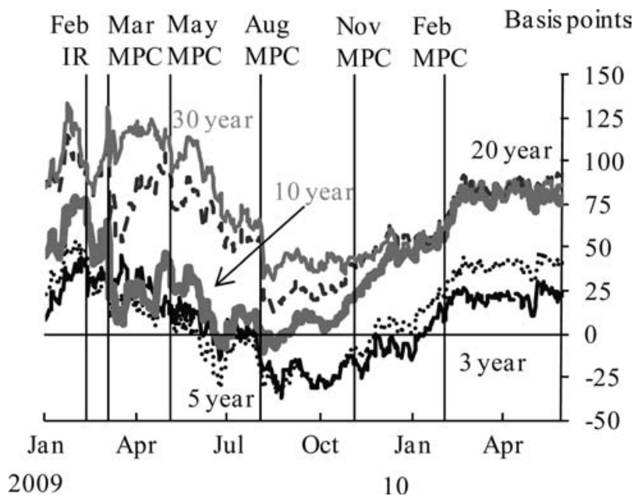
[11] See www.dmo.gov.uk/doc/gilts/press/sa060809b.pdf.

Figure 2. Gilt Yields[a]



[a]Estimated zero-coupon spot rates.
Sources: Bloomberg and Bank of England.

Figure 3. Gilt-OIS Spreads[a]



[a]Estimated zero-coupon gilt spot rates less corresponding zero-coupon OIS spot rates.
Sources: Bloomberg and Bank of England.

impact of QE on gilt yields, given the amount of other news there has been over the period, including on the likely scale of future gilt issuance by the UK government.

In the rest of this section we look at two different, but related, methods of quantifying the impact of QE on gilt yields. First, we use an event-study approach based on summing up the reactions of gilt yields and gilt-OIS spreads to announcements about QE. Second, we use a calibration based on scaling up reactions to the estimated news about total QE in those announcements, using the results of a survey of City economists conducted by Reuters.

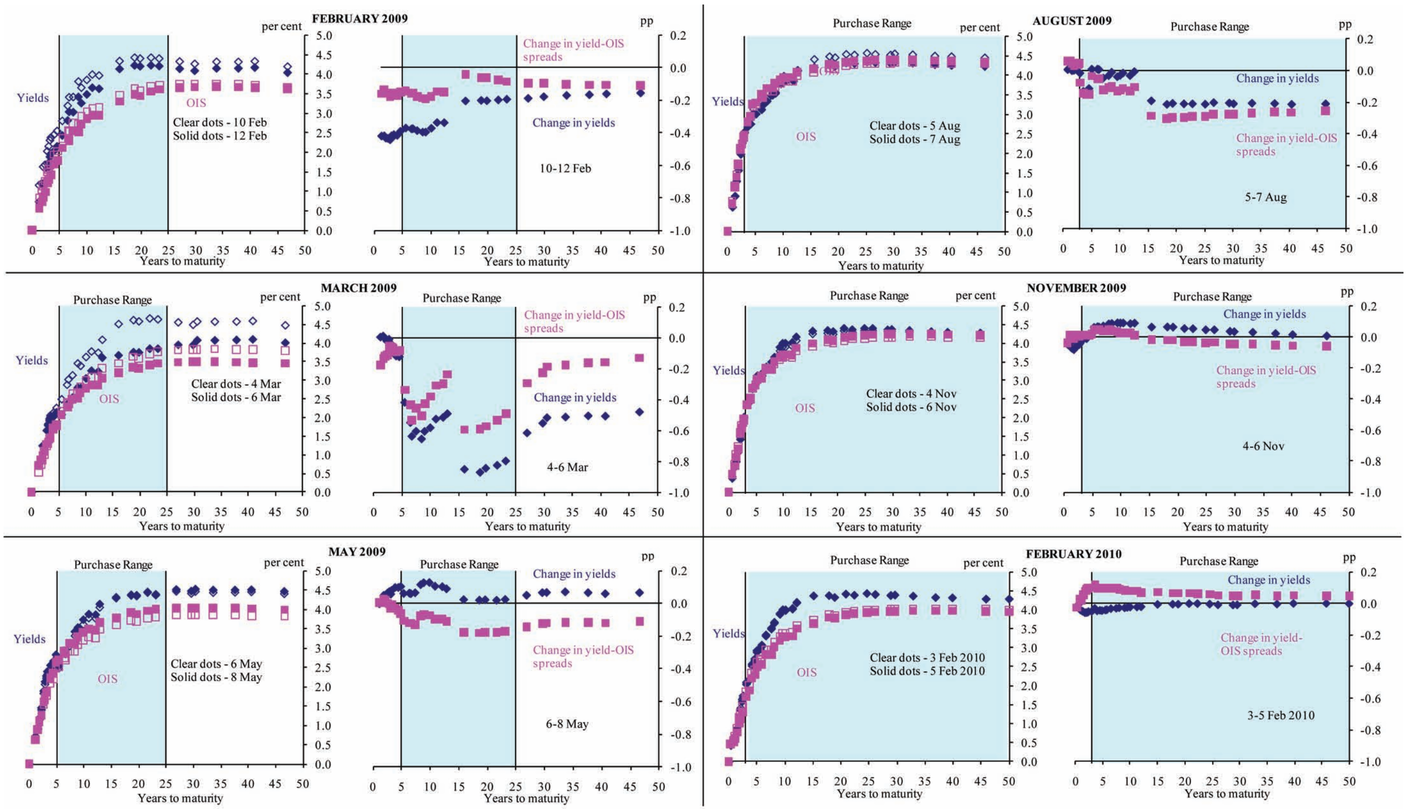
4.1 Event-Study Analysis

We might expect the majority of the impact of QE purchases on gilt yields to occur not when purchases are actually made but when expectations of those purchases are formed. One way, therefore, of quantifying the impact is to look at the immediate reaction of gilt yields and OIS rates to announcements relating to QE purchases (a similar approach is used in Bernanke, Reinhart, and Sack 2004 and Gagnon et al. 2011).

This event-study method involves focusing on the reaction of market prices over a fairly narrow interval after the QE-related news is released, with the aim of capturing the market's direct reaction to the news, abstracting from other factors that may also have been affecting asset prices. One judgment is how large to make the time interval (window) for comparison. Too short and we risk missing the full market reaction, as it may take time for the market to evaluate the news; too long and we risk the estimated reaction being contaminated by other news events. In what follows we use a two-day window, but for robustness we also examine the impact of using one- and three-day windows below. The relative novelty of QE in the United Kingdom, and the fact that market functioning may have been impaired, at least in early 2009, suggests that using a much shorter (intraday) window would not be appropriate.

Figure 4 shows the reaction of individual gilts to the six pieces of QE news discussed in section 3, as six pairs of figures. The left-hand figure in each pair shows yields-to-maturity at the end of the day before each announcement (clear diamonds) and on the day after the announcement (solid diamonds) corresponding to a two-day window. We also show equivalent OIS rates (clear and solid squares) for

Figure 4. Gilt Yield to Maturities and Corresponding Duration-Matched Zero-Coupon OIS Rates (Left Panel) and the Changes in Those Yields and the Yield-OIS Spread (Right Panel) Before and After Announcements Relating to QE Purchases



Sources: Bloomberg and Bank of England.

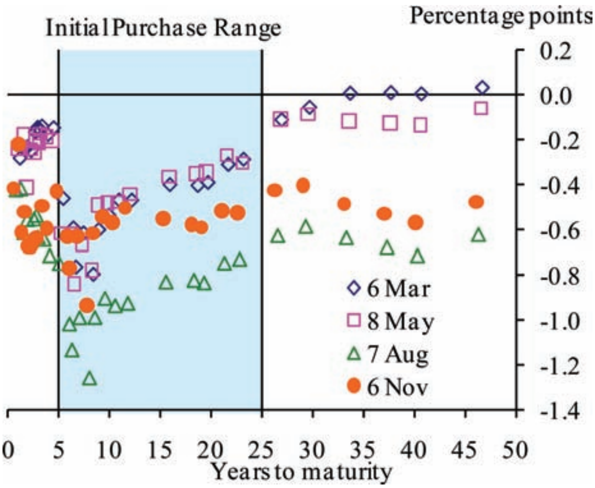
both days, where we have derived zero-coupon OIS rates from end-of-day prices to match the duration of each individual bond. The right-hand figure in each pair shows the corresponding change in gilt yields (diamonds) and the change in the spread between gilt yields and OIS rates (squares).

The largest two-day yield movements occurred following the publication of the Bank's Inflation Report and associated press conference in February 2009 and the announcement of the commencement of QE purchases after the March MPC meeting.

In February there was a reaction in both bond yields and gilt-OIS spreads, with yields on shorter-dated gilts falling by as much as 50 basis points (see figure 4, top-left panel). The reaction of yields on bonds with maturities above ten years was noticeably less. Intelligence gathered by the Bank of England from market participants suggested that some of this reflected perceptions that the Bank would target purchases on shorter-maturity bonds (see also Oakley 2009). The fact that both OIS rates and gilt-OIS spreads fell suggests that the news in the Inflation Report and the associated press conference comprised both macro/policy news and expected portfolio balance effects. Of course, not all of this macro/policy news reaction can be attributed to QE. Market intelligence and surveys suggest that the publication of the February Inflation Report was also associated with an increased expectation that the Bank Rate would be cut to 0.5 percent in March, though the impact of that on longer-term yields is likely to have been small.

When the MPC announced in March 2009 that the Bank would purchase up to £75 billion of gilts with residual maturities of between five and twenty-five years, there was a further significant reaction in yields and OIS rates (figure 4, middle-left panel). This effect was most pronounced in fifteen- to twenty-year maturities where yields fell by up to 80 basis points, perhaps reflecting a correction of previous expectations that purchases would be concentrated in gilts with shorter maturities. OIS rates also fell, though not as sharply, suggesting that the bulk of the fall reflected expected portfolio balance effects rather than changes in expected future short-term interest rates or the risks around those rates. Again the announcement accompanied other news, in that the Bank Rate was also reduced to 0.5 percent, but this change had been widely expected and any resulting reactions were likely to have been confined to the short end of the yield curve.

Figure 5. Cumulative Changes in Gilt-OIS Spreads Since February 10, 2009



Sources: Bloomberg and Bank of England.

The announcement in May 2009 of an extension of QE to £125 billion of purchases was widely anticipated and there was little reaction, with gilt yields and OIS rates actually rising by a small amount (figure 4, bottom-left panel). The August 2009 announcement of a further £50 billion extension was also largely expected, and the accompanying fall in yields of longer-maturity bonds seems more likely to have been caused by the extension of the purchase range to all bonds with a residual maturity of more than three years rather than news about the absolute size of purchases themselves (figure 4, top-right panel). Again the fact that this fall in yields was not reflected in OIS rates suggests that it was caused by a portfolio balance effect. The last two pieces of QE-related news appear to have had relatively little impact. The further extension of the program to £200 billion in November 2009 and the decision to pause purchases in February 2010 were both widely anticipated and so contained little news for prices (figure 4, middle and bottom-right panels).

The combined reaction to the February and March 2009 announcements was concentrated in those gilts within the five- to twenty-five-year purchase range. This changed the shape of the yield curve and introduced noticeable kinks around the five- and twenty-five-year points. Figure 5 shows the cumulative change in gilt-OIS spreads from before the February 2009 announcement to after the March, May, August, and November 2009 announcements. From this we can see that those differences in relative spreads were still present following the widening of the maturity range in August 2009. The fact that these differences were not arbitraged away by those who are broadly indifferent between gilts with similar maturities is indicative of increased segmentation in the gilt market and a lack of arbitrage activity in the first half of 2009. This suggests that, for those gilts in the initial purchase range, the downward pressure from QE purchases on their yields was greater than for other gilts. But figure 5 also shows that by November 2009 those differences had diminished. As described in section 3, the period between August and November saw the APF begin a scheme to lend out the gilts it had purchased via the DMO. The increased ability to borrow and short sell more easily those gilts held by the APF may have helped the arbitrage process, reducing segmentation in the gilt market. In so doing, the impact of QE on yields is likely to have been spread more evenly across gilts.[12]

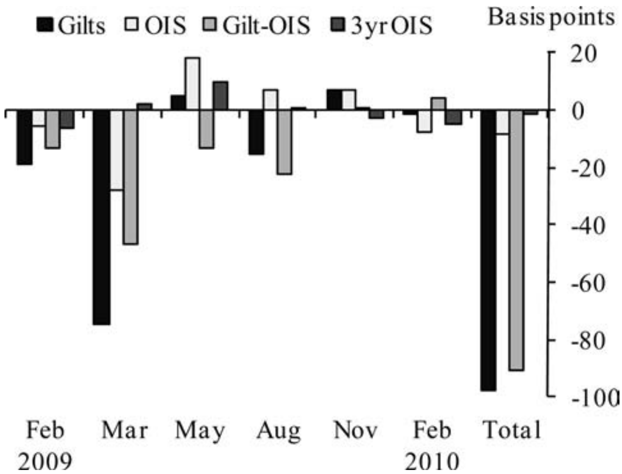
In order to get an estimate of the effect of the QE announcements on gilt yields, we could simply sum over those reactions to QE news. But to get a more precise read of the overall impact on the term structure, we can examine the changes in the Bank of England's estimated zero-coupon yield curves, which strip out coupons from each gilt and allow us to construct continuous curves.[13] Using these yield curves, figure 6 shows a summary of how gilts reacted to each of the six announcements over a two-day window. It focuses for simplicity on the reaction averaged across five- to twenty-five-year spot rates, reflecting the maturity range of the initial purchases.[14]

[12] Joyce et al. (2010) show that indicators of liquidity in the gilt market such as turnover and bid-ask spreads also improved over the period. This improvement in market liquidity may have been partly aided by APF gilt purchases and could also have contributed to the decrease in relative yield differences observed following August 2009.

[13] For data and more information, see www.bankofengland.co.uk/statistics/yieldcurve/index.htm.

[14] To the extent that the majority of the impact is likely to be concentrated at the duration of the gilt purchased, this could warrant focusing on the maturity range corresponding to the durations of the purchase range, or four to fifteen years. Here we attempt to capture the broader effects by using a five- to twenty-five-year range.

Figure 6. QE Announcement Impact on Gilt Yields, OIS, and Gilt-OIS Spreads: Average Change in 5- to 25-Year Spot Rates



Sources: Bloomberg and Bank of England.

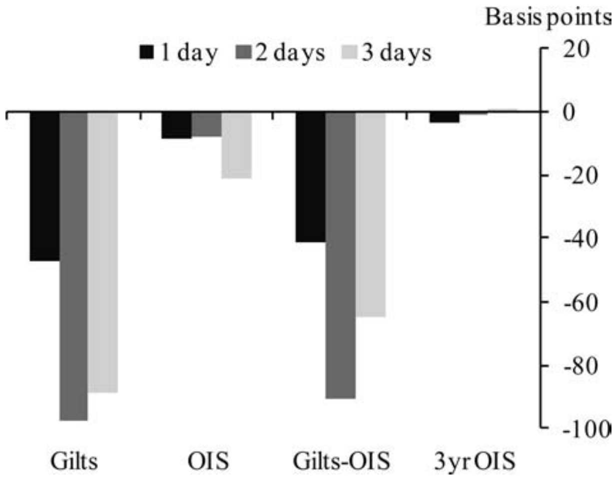
It also shows the reaction of gilt-OIS spreads and OIS rates for the same average maturities and the reaction of three-year OIS rates, in order to measure macro/policy news affecting just the short end of the yield curve. The publication of the Inflation Report in February 2009 appeared to have led markets to anticipate an additional 25-basis-point cut in the Bank Rate.[15] So to try and strip out that news from our measurement of the impact of QE, we make a simple adjustment to the reaction of gilts and OIS rates in February.[16]

Summing over the reactions in gilt yields to each of the QE news events gives an overall average fall of just under 100 basis points—with reactions ranging between 55 and 120 basis points across the five- to twenty-five-year segment of the yield curve (figure

[15]The mean expected level of the Bank Rate following the March MPC announcement, as measured by the Reuters poll of City economists, fell from 0.73 percent on February 5 to 0.53 percent on February 11.

[16]We subtract 25 basis points from instantaneous forward rates between zero and five years on a sliding scale (from 25 basis points at zero years to 0 basis points at five years) and then calculate the corresponding spot rates.

Figure 7. Total QE Announcement Impact and Sensitivity to Window Size



Sources: Bloomberg and Bank of England.

6).[17] Government bond yields in the United States, Germany, and France were largely unchanged over the same event windows, suggesting that these were UK-specific effects. The decomposition of the changes shows that the bulk of the effect came through changes in the gilt-OIS spread, which we expect to mainly reflect portfolio balance effects (as explained in section 2). The remaining change in OIS rates appears much smaller, at less than 10 basis points in total, and the overall reaction in shorter-maturity three-year OIS rates was close to zero. This suggests that the impact through the macro/policy news channel, as measured by changes in OIS rates, was much less important.

Figure 7 shows how sensitive these overall estimates are to changes in the size of the reaction window. Using a longer three-day window results in a similar overall impact, with a slightly smaller contribution from gilt-OIS spreads. Using a shorter one-day window

[17] On the basis of a very similar event-study approach, Meier (2009) suggested that the initial QE announcements reduced gilt yields by 35–60 basis points "at the very least" compared with where they would otherwise be. But his assessment only covered the period up to the middle of 2009.

reduces the overall impact to around 50 basis points, with the majority of the effect accounted for by movements in gilt-OIS spreads. So the overall impact varies between 50 basis points and 100 basis points according to the window size, but the conclusion that portfolio balance effects dominate remains robust to whatever window size is used.

4.2 News-Based Calibration

Figure 6 showed that the reactions in gilt yields were much larger for the February and March announcements than for later ones. One obvious explanation for these differences is that it reflects those first two events containing more news about QE for market participants.

An alternative way to estimate the impact on yields of QE purchases is to weight the announcement reactions by the amount of news each announcement contained. But in order to do so, it is necessary to calculate a measure of that news. Some partial information on market participants' expectations of QE is available from the Reuters poll of economists, which regularly surveys a panel of about fifty City economists on their future Bank Rate expectations. Between April 1, 2009 and February 25, 2010, Reuters also included a question in its poll on the total amount of QE purchases respondents expected. Bank of England market intelligence suggested that the responses to this survey provided a good proxy for market expectations of QE.

We can calculate a measure of the news in each announcement as the difference between the total QE purchase amount expected in the survey preceding the MPC's decision and the total QE amount expected in the survey released immediately after the MPC's decision. In the cases where there was no survey conducted immediately after the announcement, we use the difference between the amount announced and the previous survey expectation as our measure of news. There was no question on expectations of QE purchases in the Reuters surveys before April 2009, so any assumption about the news in the February and March 2009 announcements is necessarily arbitrary. But as most QE news appears to have occurred during this period, it is necessary to include it in our sample. Our baseline assumption is that the total amount of QE expected in the Reuters April 2009 survey represented genuine news, which was distributed equally between the February and March announcements. This is a conservative assumption as, to the extent that QE was anticipated before February and March, the amount of news will be overstated and hence the sensitivity of yields to that news understated. According to the Reuters survey, the February 2010 decision was broadly expected, as the mean of the Reuters survey was £204 billion before the announcement and £205 billion afterwards. For that reason, we do not include that announcement in the calibration.

To calibrate the impact of QE on the yield curve, we compare the two-day change in zero-coupon gilt and OIS rates across maturities of five to twenty-five years with our news measure for the QE events in February, March, May, August, and November 2009 and for the October 2009 Q3 GDP release.[18] Figure 8 shows there is a strong relationship between the size of the news and the average change in gilt yields across maturities after each event. A simple OLS regression of the two suggests a fall in gilt yields of around 0.6 basis points for each additional £1 billion of unanticipated QE purchases announced.[19]

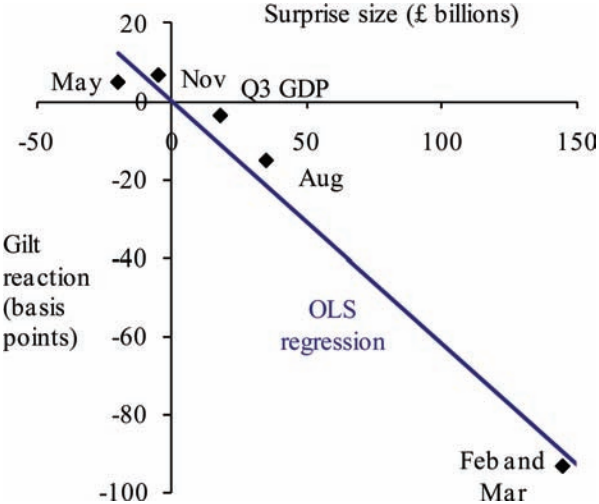
Scaling up the estimates from OLS regressions of QE news on gilt yields, OIS rates, and the gilt-OIS spread, figure 9 shows the total estimated impact of QE purchases averaged across maturities. The total impact on gilt yields from this news-based calibration is estimated to be around 125 basis points when a two-day window is used, with an impact on OIS rates (macro/policy news channel) of around 45 basis points and on gilt-OIS spreads (portfolio balance channel) of 80 basis points. This overall estimate is broadly similar to that estimated previously by summing up the announcement reactions, and the dominant effect is again estimated to come through the portfolio balance channel.

A sensitivity analysis of the results to the window length shows that, like before, the overall estimated impact is similar when we use two or three days, and smaller with a one-day window. The breakdown into changes in OIS rates and gilt-OIS spreads remains broadly

[18]The rise in expected purchases between the Reuters surveys on October 1 and October 28, 2009 appears to have been attributable to a lower-than-expected preliminary GDP release on October 23, which suggested more QE might be necessary.

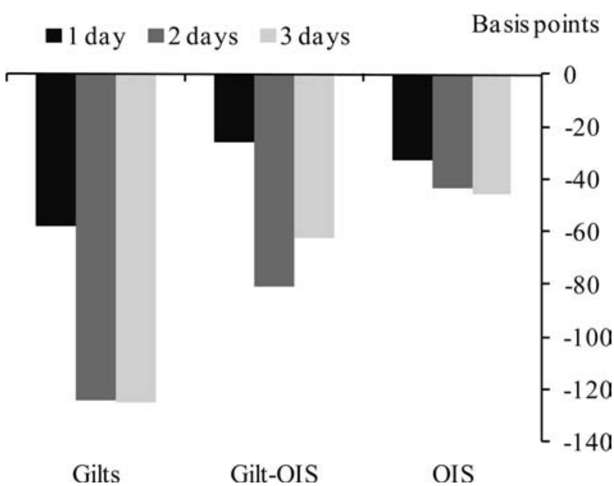
[19]The standard error for the coefficient is 0.04 and the R^2 is 0.98.

Figure 8. Size of Surprise and Average Gilt Movements



Sources: Thomson Reuters Datastream and Bank of England.

Figure 9. News-Based Calibration Impact and Sensitivity to Window Size



Sources: Thomson Reuters Datastream, Bloomberg, and Bank of England.

unchanged when we estimate the simple OLS regression using a two- or a three-day window. Using a one-day window, by contrast, results in a relatively larger impact on OIS rates than on gilt-OIS spreads.

5. The Reaction of Other Assets[20]

To the extent that investors do not regard money as a perfect substitute for gilts, we would expect them to reduce their money holdings associated with QE purchases by buying other sterling assets, such as corporate bonds and equities, and foreign assets. This will likely put upward pressure on the prices of those assets, and perhaps downward pressure on the sterling exchange rate. In addition, announcements about QE may contain information about the economy that has implications for perceptions of future corporate earnings and the uncertainty around them; and changes in the prices of gilts may affect the rate at which investors discount future cash flows. Both of these effects will also have an impact on asset prices. But all of these effects might be expected to take time to feed through, as it will take time for investors and asset managers to rebalance their portfolios, and asset prices are unlikely to anticipate fully this process, given the novelty of QE and uncertainty about the transmission mechanism.

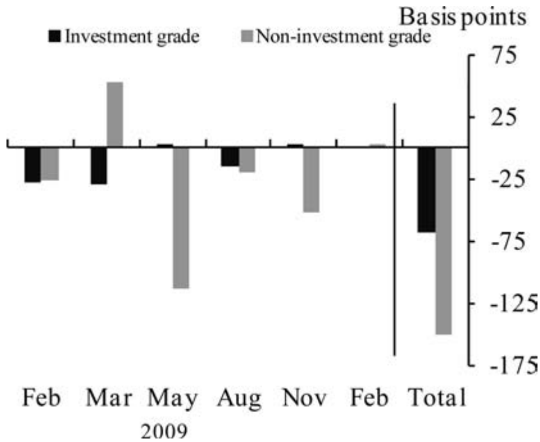
This section focuses on assessing the observed impact of QE on the two largest sterling asset classes in addition to gilts—corporate bonds and equities—and the impact on the exchange rate. Figures 10 and 11 summarize the immediate price reaction (over two days) following each of the six QE news announcements discussed earlier. These suggest that equity and corporate bond prices reacted in a less uniform way than gilts after the announcements. The rest of this section discusses each asset class in more detail.

5.1 Corporate Bonds

Lower gilt yields should lead to lower corporate bond yields for a given corporate bond spread (compensating for the risks of holding sterling corporate bonds relative to gilts). But, in addition, as

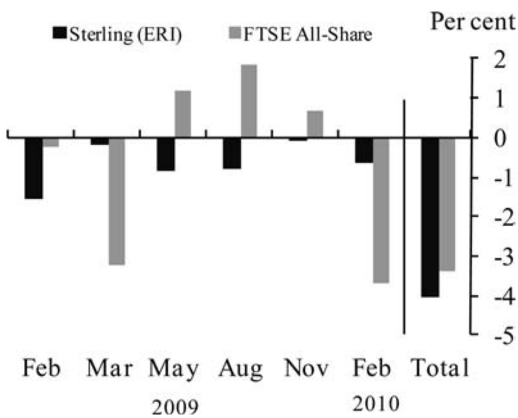
[20] A more detailed discussion of the reaction of other asset prices can be found in Joyce et al. (2010).

Figure 10. QE Impact on Corporate Bond Yields



Source: Merrill Lynch.

Figure 11. QE Impact on Sterling and FTSE All-Share



Source: Bloomberg.

investors attempt to rebalance their portfolios away from gilts and into corporate bonds, the component of that spread representing compensation for risk aversion and uncertainty (the so-called debt risk premium) should fall, reducing yields further, though the timing of this could depend on how long investors take to make portfolio decisions. But the announcement of QE may also give investors information about the outlook for the economy. This, if worse than expected, could affect the perceived risk of corporate default, putting upward pressure on yields. Over time, however, a successful QE policy would be expected to lead to lower corporate bond yields.

Summing over the immediate reaction to the six QE news announcements, sterling investment-grade corporate bond yields fell by 70 basis points, with spreads remaining broadly flat (figure 10). Sterling non-investment-grade corporate bond yields fell by 150 basis points, with spreads narrowing by 75 basis points.[21] The narrowing in non-investment-grade spreads is consistent with QE removing some of the perceived downside tail risks. Over the same announcement windows, U.S. dollar and euro-denominated investment-grade bond yields fell by 23 basis points and 11 basis points, respectively, around 50 basis points less than sterling-denominated bonds, suggesting that there was a UK-specific effect.

5.2 Equities

Lower gilt yields should, all else equal, increase the present value of future dividends, thus raising equity prices. In addition, as investors attempt to rebalance their portfolios away from gilts towards more risky assets, the additional compensation investors demand for the risk of holding equities (the so-called equity risk premium) should fall. This will put further upward pressure on equity prices. Again, the announcement of QE may also give investors information about the outlook for the economy. If worse than expected, this could lower their immediate expectations for future dividends and raise risk premia, thus putting downward pressure on equity prices in the short term. So, as for corporate bonds, it is therefore not clear what we would expect the immediate QE impact to be, although a successful QE policy would eventually be expected to lead to higher equity prices.

Equity prices did not react in a uniform way in response to QE news (figure 11). The FTSE All-Share Index fell slightly (−0.2 percent) following the publication of the February Inflation Report and more sharply (−3.2 percent) following the March MPC announcement. However, over the same period, international equity prices fell by even more, suggesting that there might have been a small positive

[21] These numbers imply gilt yields fell by 75 basis points. This is different from the estimate in section 4 because the average duration of corporate bonds is shorter than that for gilts.

UK-specific effect. UK equity prices increased somewhat following the next three QE announcements but fell sharply in February 2010, though this is unlikely to have been a QE effect, as the February decision was widely expected.

5.3 Sterling

Lower gilt yields should, all else equal, lead to a depreciation of sterling. A standard uncovered interest parity (UIP) decomposition would predict an 8 percent depreciation given the observed fall in ten-year spot gilt yields over the QE news events.[22] Summing over the immediate reactions to the six QE news announcements, the sterling exchange rate index (sterling ERI) depreciated by 4.0 percent overall (figure 11)—although the largest fall occurred after the publication of the February Inflation Report, which may not solely reflect QE news. If we instead perform a UIP decomposition using three-year OIS rates, in order to isolate the macro/policy news component, the implied fall in the exchange rate would be only 0.5 percent, which would imply that the initial reaction of sterling was slightly greater than expected.

5.4 Summary

Table 2 summarizes the movements in asset prices and yields around the main QE announcements and over a longer period up to mid-2010. Medium to long-term gilt yields appear to be 100–125 basis points lower than in the absence of QE, with most of the effect coming through the portfolio balance channel. Corporate bond yields also fell markedly around announcements, and there were modest falls in sterling. For equities, the impact of QE is harder to pinpoint, though equity prices rose strongly through 2009.

In addition to those immediate reactions, the impact on other asset prices through the portfolio balance channel may come through over a more prolonged period, as investors make decisions about how to rebalance their portfolios. Table 2 shows that between March 2009 and May 2010 sterling investment-grade bond spreads narrowed by 380 basis points and the FTSE All-Share Index rose by

[22] For an explanation of UIP see Brigden, Martin, and Salmon (1997).

Table 2. Summary of Movements for Different Assets

Asset	Change Around Announcements	Change March 4, 2009–May 31, 2010	Comments
Gilts	−100 bp (of which −90 in gilt-OIS spreads)	+30 bp (of which +15 in gilt-OIS spreads)	The portfolio balance channel dominates the macro/policy news channel.
Gilts (Surprise Calibration)	−125 bp (of which −80 in gilt-OIS spreads)	+30 bp (of which +15 in gilt-OIS spreads)	The portfolio balance channel also dominates when allowing for surprise component of announcements.
Corporate Bonds (Investment Grade)	−70 bp	−400 bp	Smaller fall than in gilts around announcements due to shorter average maturity; spreads flat around announcements but significantly down over the period.
Corporate Yields (High Yield)	−150 bp	−2,000 bp	Larger announcement effects, possibly reflecting the removal of tail risk.
FTSE All-Share	−3 percent	+50 percent	No announcement effects, but prices up during the period.
Sterling ERI	−4 percent	+1 percent	Hard to single out QE effect.

around 50 percent. All else being equal, higher equity and corporate bond prices are likely to encourage firms to raise finance through relatively higher capital market issuance, either in addition to or as a substitute for alternative means of raising funds. Net equity issuance by UK private non-financial corporations (PNFCs) was particularly strong in 2009, reversing the negative net issuance observed over 2003–08. Net corporate bond issuance by UK private non-financial corporations in 2009 was also stronger than over the 2003–08 period. It is not possible to know what would have happened in the absence of QE, but Bank of England market intelligence suggested there was strong institutional investor demand for corporate bonds during the second half of 2009 (see Bank of England 2009).

6. Portfolio Model Estimates

Our analysis of the reaction of asset prices to the MPC's QE announcements suggests that a large part of the effect came through a portfolio balance channel. But we have also noted that it is difficult to quantify the specific impact of QE, given the potential role of other policies and international factors. As an alternative approach, in this section we estimate two different portfolio balance models in order to quantify the possible effects of the MPC's asset purchases on asset prices.

6.1 The Portfolio Balance Model

A natural starting point for modeling the portfolio channel is the basic portfolio choice model arising from the "mean-variance" approach to portfolio allocation developed by Tobin and Markovitz in the 1950s (e.g., Tobin 1958) and set out in a number of papers, including Roley (1979, 1982), Walsh (1982), and Frankel (1985). In this model, expected returns on each asset are exogenous, from the perspective of each individual investor. An individual investor's problem is to choose the weight to allocate to each asset in his or her portfolio, in order to maximize expected utility from end-of-period wealth, subject to a wealth constraint. In aggregate, however, investors' total asset holdings are constrained to match the available (exogenous) asset supplies of each asset. In the case where investors' total desired asset holdings do not match the available asset supplies, investors will require additional returns on each asset to willingly hold the "excess" asset stocks, and vice versa. This provides a lever for a policy of asset purchases to affect asset prices by changing asset quantities (specifically, reducing the quantity of gilts) and thereby the excess returns (risk premia) investors require ex ante to hold the available stock of assets (in the case of QE purchases, reducing the required returns on gilts and assets that are substitutable for gilts).

The first-order conditions of the investor's maximization problem in the basic model generate a relationship between investors' asset demands, excess returns of each asset, and their covariances. By equating asset demands with exogenous asset supplies, it is then possible to derive the following equilibrium condition:

$$E_t(r_{t+1}) = \lambda\Omega\alpha_t, \tag{6}$$

where r_{t+1} is a vector of expected excess asset returns (where one of the assets performs the role of the numeraire asset), λ is the coefficient of constant relative risk aversion (CRRA), Ω is the covariance matrix of asset returns, and α_t is a vector of asset shares of the total portfolio. Equation (6) shows that expected returns on each asset in excess of the return on a benchmark asset are a function of risk aversion, the share of each asset in total wealth, and the asset return covariances.

In this simple model, given a set of asset shares, the expected excess returns are completely determined by the variance-covariance matrix of asset returns and the covariances capture relative substitutability between different assets. The model implies that the impact of a change in the relative stocks of assets—brought about by a swap of money for gilts, for example—is given by the covariance between asset returns together with the CRRA coefficient. This suggests that one might calibrate the impact of the Bank's asset purchases by estimating the return covariances and assuming a value for the coefficient of relative risk aversion. We follow this approach below.

It needs to be recognized, of course, that the model adopts a number of simplifying assumptions. There are a range of other important influences on asset returns, in addition to asset supplies, that are not captured by this model (e.g., the business cycle). Furthermore, the model is partial equilibrium in nature. Nevertheless, it seems surprisingly robust to various extensions (see Campbell 1999).

How do we implement this basic model empirically? We do not observe ex ante returns, so we shall assume in what follows that investors have rational expectations, so that the difference between ex post excess returns and ex ante excess returns is measured by a random error, orthogonal to the portfolio shares:[23]

$$r_{t+1} - E_t r_{t+1} = \varepsilon_{t+1}, \quad E_t(\varepsilon_{t+1}) = 0, \quad E_t(\varepsilon_{t+1}|\alpha_t) = 0.$$

Adding a constant term, we can therefore write the basic empirical model as (see, e.g., Engel et al. 1995 or Hess 1999 for a derivation):

$$r_{t+1} = A + \lambda \Omega_t \alpha_t + \varepsilon_{t+1}, \quad \Omega_t = E_t \varepsilon_{t+1} \varepsilon'_{t+1}. \tag{7}$$

We shall look at two different models: a basic vector autoregressive (VAR) model informed by the theory, but where we allow the data to speak, and a more sophisticated multivariate generalized autoregressive conditional heteroskedasticity (GARCH)-in-mean model (henceforth GARCH-M model), where we impose more structure using the theoretical restrictions implied by the basic theory.

6.2 A VAR Application

Our first approach is largely data driven. We estimate a VAR which includes both excess returns and asset shares and also allows for the influence of a set of exogenous variables, intended to capture other influences on asset demand and supply. The virtue of this approach is that it allows asset supplies to be treated as endogenous and to respond to movements in excess returns.[24]

Our VAR takes the following general form:

$$Y_t = \alpha_+ \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{k} \gamma_j X_{t-j} + \varepsilon_t, \tag{8}$$

where Y_t is the vector of endogenous variables, which consists of both monthly excess returns and shares of total wealth held in these assets, and X_t is a vector of exogenous variables. In this model the

[23]If there are other information variables, then the errors would be orthogonal to the overall information set, which would include the portfolio shares.

[24]However, it is a reduced-form model and therefore subject to the usual caveats.

Table 3. Monthly Asset Returns and Asset Shares: Summary Statistics

	Mean	Standard Deviation	Min.	Max.
Excess Return on Equities (pp)	0.570	3.896	−12.743	10.053
Excess Return on Corporate Bonds (pp)	0.408	1.450	−3.759	4.648
Excess Return on Gilts (pp)	0.339	1.478	−4.127	4.933
Return on M4 (pp)	0.323	0.104	0.199	0.764
Equity Share	0.500	0.0442	0.411	0.600
Corporate Bond Share	0.0648	0.0290	0.020	0.109
Gilt Share	0.0927	0.0152	0.070	0.120
M4 Share	0.343	0.040	0.269	0.453

Notes: Sample is December 1990 to June 2007. Excess returns are calculated relative to the return on M4.

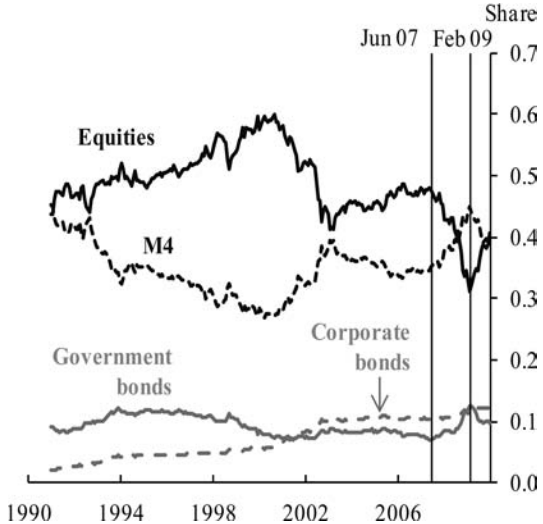
return covariances are implicit in the model estimates, rather than being explicitly modeled.

In our baseline model, we included monthly returns on gilts, sterling investment-grade corporate bonds, UK equities, and M4, with the latter defined as the numeraire asset. Details of the construction of the asset price and asset stock data are contained in the data appendix. For our exogenous variables we included variables attempting to pick up the state of the economic cycle: the growth rate of industrial production, (seasonally adjusted) RPI inflation, and the slope of the yield curve.[25]

Summary statistics for the asset price return and share data for the period December 1990 to June 2007 are shown in table 3; the asset shares are also plotted in figure 12. As we would expect, riskier assets tend to earn higher returns on average, so the average monthly return on equity is nearly three times as large as the return on holding M4. The volatility of corporate bond returns is slightly lower

[25] An extended version of the model including index-linked bonds produced similar results.

Figure 12. Asset Shares



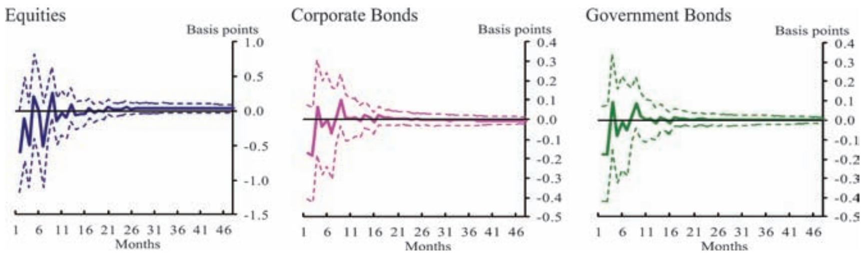
Sources: Thomson Reuters Datastream, Barclays Capital, and Bank calculations.

than gilt returns, at least for our sample, though the average return is slightly higher. One striking feature of the asset share data is the strong inverse relationship between the M4 share and the equity share (figure 12).

We estimated the model by OLS using monthly data on a sample from December 1991 to the middle of 2007, so before the onset of the current global financial crisis. We used seven lags of each endogenous variable, in line with the results from the normal Akaike and Schwarz lag selection criteria, and checked that post-estimation diagnostics including stability tests were satisfactory.[26] We then used the model to produce impulse responses, which allow us to summarize how excess asset returns and asset supplies are predicted to respond to a shock to the share of gilts in the aggregate portfolio. When conducting impulse response analysis, an important concern is the method used to identify shocks corresponding to each of the endogenous

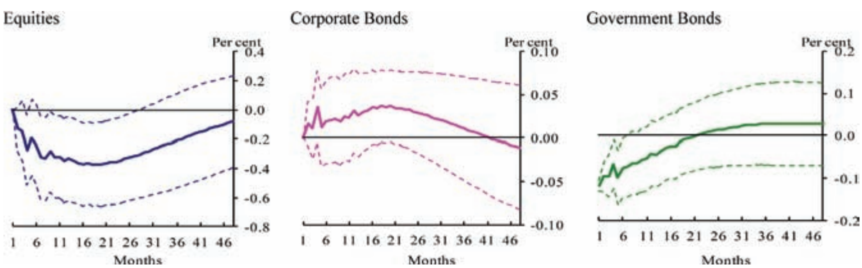
[26]The VAR was found to be stable with no roots outside the unit circle. Full estimation results are available upon request.

Figure 13. Impulse Responses of Excess Returns (One-Standard-Deviation Fall in Gilt Share)



Note: Excess returns are calculated relative to the return on M4.

Figure 14. Impulse Responses of Asset Shares (One-Standard-Deviation Fall in Gilt Share)



variables in the VAR. For our analysis, innovations to the gilt share are interpreted as the QE shock and this is identified in a standard recursive manner, by ordering the gilt share last in the VAR. We apply a Cholesky decomposition to compute the impulse responses.

Figures 13 and 14 show the impulse response functions for a one-standard-deviation fall in the share of gilts (offset by an increase in the share of M4). As the theory would suggest, the expected excess returns on gilts, corporate bonds, and equities all fall in response (although these responses are within the 95 percent confidence interval). This would be consistent with a rise in asset prices, as investors try to reallocate their portfolios away from gilts. The response of quantities to this shock is puzzling, however. While the corporate bond share increases slightly and the share of gilts falls, as might be expected, the share of equities also falls. This result is difficult to reconcile with the portfolio balance approach but might reflect the

Table 4. Estimated Impact of QE on Annualized Excess Returns (Basis Points)

	VAR Model		Multivariate GARCH-in-Mean (CCRA = 3)
	Immediate Impact	**Average Over Six Months**	**Effect**
Excess Returns on Gilts	−85	−32	−70
Excess Returns on Corporate Bonds	−81	−32	−66
Excess Returns on Equities	−282	−121	−34

Note: Excess returns are calculated relative to the return on M4.

fact that over our sample the share of M4 in wealth moved inversely with the share of equity.

The impulse responses are based on a one-standard-deviation shock, which translates roughly into a reduction of £5 billion of gilts using the gilt share sample average. In order to scale up these numbers to simulate the MPC's asset purchases, we assume for simplicity that all the purchases were from non-bank domestic investors (so that all the gilt purchases would have led to additional broad money holdings, at least initially) and were implemented at the start of the period.[27] The assumption that all the purchases come from the domestic non-bank private sector means that our estimates are likely to overestimate the effects, if anything.

To make the results more comparable with the changes in (annualized) yields shown earlier, table 4 shows the model-implied impact of QE in terms of annualized excess returns. Given uncertainty over the VAR dynamics, it is difficult to know which horizon to focus on. The second and third columns of the table therefore provide two measures of the implied impact on annualized monthly excess

[27]Actual QE announcements and purchases were staggered over a longer period, so we place less emphasis on the precise dynamics of the impulse responses.

returns: in the first period after the shock and on average over the first six months after the shock. The range of estimates for both excess gilt returns and excess corporate bond returns is broadly similar to the immediate market reactions discussed in sections 4 and 5. The range of estimates for excess equity returns is clearly much greater and is also more difficult to compare directly with the earlier analysis. Using a dividend discount model (as in Inkinen, Stringa, and Voutsinou 2010) to map the range of estimates into prices, however, implies a rise of between 20 percent and 70 percent. The upper estimate is clearly implausible. The main conclusion we draw is that the suggested impact on equity prices is potentially large but highly uncertain.

6.3 A Multivariate GARCH-in-Mean Model

One important caveat regarding our unrestricted VAR model is that it implicitly assumes that the covariance matrix between asset returns is constant. That is at odds with the empirical literature, which suggests that covariances can vary substantially over time and in particular at times of financial stress. So the model does not take into account the fact that the degree of substitutability of the different assets will have changed in response to evolving market conditions.

To allow explicitly for the possibility that the covariance matrix of asset returns may be changing over time, we also estimated the portfolio balance model in (7) using a multivariate GARCH-M framework (see Engel et al. 1995). This approach allows us to estimate a time-varying covariance structure but treats asset shares as exogenous. The estimated model takes the following form for an n-asset portfolio:

$$r_{t+1} = A + \lambda \Omega_t \alpha_t + \varepsilon_{t+1} \tag{9}$$

$$\Omega_t = C^{*'} C^* + A^{*'} \varepsilon_t \varepsilon_t' A^* + B^{*'} \Omega_{t-1} B^*. \tag{10}$$

The covariance structure given in (10) is the first-order BEKK model of Engle and Kroner (1995), where C^*, A^*, and B^* are $(N \times N)$ coefficient matrices with C^* upper triangular. The quadratic structure of the BEKK model ensures that the covariance matrix is positive

Table 5. Estimation Results for Multivariate GARCH-M Model, CRRA = 3

Mean Equation Estimates of the Constant Vector—*A*			
	Coefficient	**Robust Standard Error**	**Significance**
A (1)	0.00739	0.00277	0.00766
A (2)	0.00343	0.00089	0.00012
A (3)	0.00281	0.00092	0.00218
MVGARCH Equation Estimates of the Upper Triangular Matrix—C^*			
	Coefficient	**Robust Standard Error**	**Significance**
C^* (1,1)	−0.0037	0.00315	0.23923
C^* (2,1)	−0.00413	0.00105	0.00007
C^* (2,2)	−0.00005	0.00073	0.94001
C^* (3,1)	−0.00474	0.00117	0.00005
C^* (3,2)	−0.00006	0.00084	0.94155
C^* (3,3)	0.00000	0.00003	0.99946

(continued)

definite. The model is estimated by maximum likelihood assuming conditional normal errors.

We first estimated the model over the same pre-crisis sample period as the VAR model, in order to infer what the model would imply for the impact of a purchase of £200 billion of gilts. When the model was freely estimated, the CRRA parameter was negative, so following Hess (1999) we restricted this coefficient to three. The reported model fits the data reasonably well and there was no residual serial correlation.[28] Table 5 contains the estimation results. It needs to be borne in mind that a larger risk parameter would generate larger changes in expected returns.

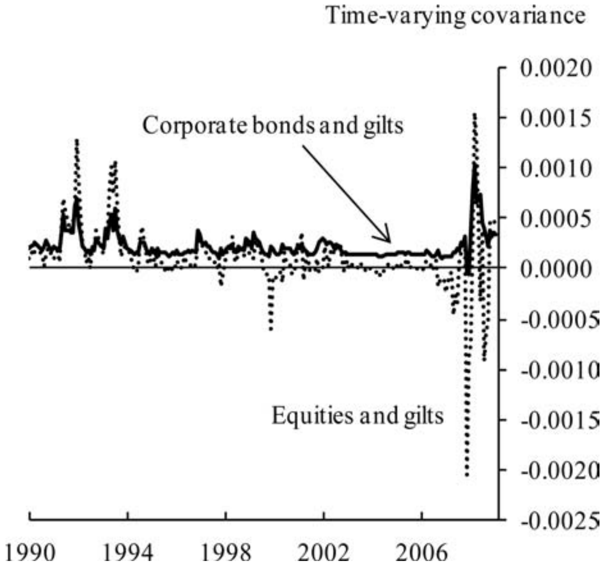
[28]In addition, we estimated a constant variance version of the model, by constraining the A^* and B^* matrices in (10) to be zero, but the null hypothesis that these parameters were zero was rejected at the 1 percent significance level.

Table 5. (Continued)

MVGARCH Equation							
Estimates of A^* Coefficient Matrix				**Estimates of B^* Coefficient Matrix**			
	Coefficient	**Robust Standard Error**	**Significance**		**Coefficient**	**Robust Standard Error**	**Significance**
A^* (1,1)	−0.43875	0.08090	0.00000	B^* (1,1)	−0.87862	0.04395	0.00000
A^* (2,1)	4.75812	1.22264	0.00010	B^* (2,1)	0.57410	0.40295	0.15423
A^* (3,1)	−4.72806	1.00346	0.00000	B^* (3,1)	−0.44677	0.48136	0.35333
A^* (1,2)	−0.01534	0.03121	0.62319	B^* (1,2)	−0.01359	0.01812	0.45320
A^* (2,2)	−0.40588	0.24215	0.09372	B^* (2,2)	−1.16749	0.05379	0.00000
A^* (3,2)	0.11543	0.24374	0.63579	B^* (3,2)	0.27857	0.06350	0.00001
A^* (1,3)	−0.01468	0.03706	0.69189	B^* (1,3)	−0.01263	0.02148	0.55659
A^* (2,3)	−0.84641	0.29500	0.00412	B^* (2,3)	−0.26368	0.08231	0.00136
A^* (3,3)	0.51189	0.30562	0.09395	B^* (3,3)	−0.61339	0.09044	0.00000
Log Likelihood	1821.48630						
Multivariate Q-stats							
Residuals from MVGARCH-in-Mean Model				**Standardized Residuals from MVGARCH-in-Mean Model**			
	Value	**Significance**	**χ^2 d.f.**		**Value**	**Significance**	**χ^2 d.f.**
Q(15)	139.50447	0.37767	135	Q(15)	142.43259	0.31395	135
Q(10)	106.71997	0.11020	90	Q(10)	88.73314	0.51799	90
Q(5)	60.46782	0.06147	45	Q(5)	53.36486	0.18362	45

Notes: Model was estimated using monthly data from 1990:01 to 2007:06. “Multivariate Q-stats” is the Hosking (1981) variant on the multivariate Q-stats.

Figure 15. Covariances between Equity and Gilt Excess Returns and between Corporate Bond and Gilt Excess Returns



Note: Excess returns are calculated relative to the return on M4.

To simulate the impact of QE, we make the same assumptions as before. We assume that all the gilt purchases were implemented at the start of the period and led one-for-one to additional broad money holdings, at least initially. The implications for annualized excess returns are shown in the final column of table 4, derived using the derivative of the asset demand relationship (using the average values of the estimated asset return covariances over the sample). These numbers are in the range implied by the VAR for gilts and corporate bonds but rather lower for equity returns. The fact that gilt and corporate yields move by similar amounts suggests that they are closer substitutes, which seems quite plausible.

We might expect that QE itself will have changed the covariance structure of returns. To try to examine this, we can reestimate the multivariate GARCH-M model over a longer sample up to the end of 2009. Figure 15 shows the estimated time-varying covariances between gilts and equities and gilts and corporate bonds from the model. The intensification of the financial crisis in late 2008 is clear from the large movements in both covariances over the same period. During 2009 there seems to be some reversion to normal conditions, though it is not possible to ascribe this directly to QE, given other developments over the same period.

In summary, these results lend some empirical support to the notion of imperfect asset substitutability in the portfolio choice models of Tobin and others. Given the considerable uncertainties involved, our empirical estimates seem reassuringly in line with the analysis reported in sections 4 and 5. Our estimates would suggest an effect on annualized excess gilt returns of 30 to 85 basis points, which is broadly similar to our estimates for the portfolio balance impact from our analysis of the announcement reactions. The major uncertainties concern the estimated impact on equities, where different approaches produce quite different estimates of the likely effect of QE on excess returns and the VAR-based analysis would imply a falling portfolio share.

7. Conclusions

As part of its response to the global financial crisis and a sharp downturn in economic prospects, the Bank of England's MPC began a program of quantitative easing in March 2009. Over a year, the Bank bought £200 billion of assets, most of them government securities. This paper attempts to evaluate the impact of these large purchases on financial markets.

Based on market reactions to news about QE purchases, we found that medium to long-term gilt yields were about 100 basis points lower than they would otherwise have been as a result of QE, which our estimates suggest mainly came through a portfolio balance effect. Separate econometric analysis suggests that these effects are broadly in the range that might have been expected. Analysis of announcement reactions is unlikely to capture the full effects of portfolio rebalancing on other assets, so it is difficult to disentangle the specific impact of QE purchases from other factors. But most other asset prices showed a marked recovery through 2009, suggesting that QE is likely to have had wider effects. Our econometric estimates suggested considerable uncertainty about the size of the impact, particularly regarding the impact on equity returns. Moreover, VAR-based analysis on its own would not have predicted the large pickup in equity issuance that occurred in 2009.

How do our findings compare with similar analysis of the Federal Reserve's asset purchases in the United States? Gagnon et al. (2011) estimate that the overall reduction in the ten-year term premium on U.S. Treasuries in response to the Federal Reserve's purchase program was "somewhere between 30 and 100 basis points." But in addition to this effect, they find an even more powerful effect on the yields on agency debt and agency mortgage-backed securities. Given the large range of uncertainty around these kinds of estimates, the effects of the Federal Reserve's purchases can be described as being of a similar order of magnitude to the Bank's for the United Kingdom.[29]

The effectiveness of QE asset purchases will ultimately be judged by their impact on the wider macroeconomy. Our analysis suggests that the purchases have had a significant impact on financial markets and particularly gilt yields, but there is clearly more to learn about the transmission of those effects to the wider economy.

Appendix. Data on Asset Returns and Stocks in Section 6

Our data consist of end-of-month realized returns and asset shares of four different assets: equities, corporate bonds, nominal gilts, and broad money from December 1990 to December 2009.

For *equities*, we use the total return index and market capitalization of the FTSE All-Share Index provided by Thomson Reuters Datastream. The return index includes an aggregate dividend as an incremental amount to the daily change in prices. For *corporate bonds*, we use the total return and market value of the Barclays Capital index corresponding to investment-grade corporate bonds of all maturities. The total index return includes coupon payments and paydowns in addition to changes in price. For *gilts*, we also use the

[29]The Federal Reserve's purchases of Treasuries, analyzed in Gagnon et al. (2011), were of a similar absolute size to those of the United Kingdom ($300 billion), albeit smaller compared with the overall size of the Treasuries market. Including the purchases of agency debt and agency mortgage-backed securities, however, gives a broadly similar figure as a percentage of GDP.

market value and returns from the Barclays Capital nominal gilts index, but we subtract holdings by the official sector using DMO data.[30]

We use an adjusted measure of M4 to capture the share of *broad money*[31] not held by financial institutions. M4 comprises the private sector's (i.e., the UK private sector other than monetary financial institutions (MFIs)) holdings of notes and coin, deposits, and other short-term instruments. Our adjusted M4 is constructed as M4 minus the sterling deposits of non-bank credit grantors, mortgage and housing credit corporations, bank holding companies, and other activities auxiliary to financial intermediation (intermediary offshore financial centers, or OFCs).[32] In addition, sterling deposits arising from transactions between banks or building societies and "other financial intermediaries" belonging to the same financial group are excluded from this measure of broad money.[33] Ideally, we would like to be able to exclude from our sample the equities, corporate bonds, and gilts held by MFIs and intermediary OFCs. This is not possible due to lack of available data.[34]

For the return on broad money, we construct an effective rate of return using rates and amounts from the Divisia money tables.[35] We first calculate separate retail and wholesale deposit rates from

[30]We only have data on official holdings since 2000. Since the proportion of gilts held by the official sector was small and relatively stable until 2008, we have deducted the percentage of average official holdings for 2000–01 from the pre-2000 figures.

[31]Detailed definitions of M4 and broad money are available at www.bankofengland.co.uk/mfsd/iadb/notesiadb/M4.htm. For a discussion of the economic meaning of M4, see Berry et al. (2007).

[32]A description of adjusted M4 can be found on www.bankofengland.co.uk/mfsd/iadb/notesiadb/m4adjusted.htm.

[33]Adjusted M4 is only available quarterly. We interpolate the adjustment linearly and deduct it from the monthly M4 data. Moreover, there are no adjusted data before December 1997. Given that the adjustment was stable at 10 percent of unadjusted M4 between 1998 and 2002, we deduct 10 percent from M4 for the pre-1997 period.

[34]There are data available on MFIs' holdings of some assets, but it is not possible to get their holdings of sterling investment-grade corporate bonds. No data on asset holdings by the other institutions excluded from the adjusted measure of M4 are available.

[35]This information is available from the interactive statistics database of the Bank of England.

several different deposit types in the Divisia tables.[36] We then weight those rates together into an overall deposit rate using the weightings of retail deposits, wholesale deposits, and notes and coin in M4. Notes and coin holdings yield no return.

The retail rates and weights are calculated by assuming that all deposits held by households, and non-financial corporates' sight deposits, are retail deposits. In turn, non-financial corporates' time deposits and all deposits by OFCs are considered wholesale. The weights obtained in this manner follow very closely the amounts of wholesale and retail deposits that make up M4 but for which no overall rates are available.

We only have quarterly deposit rate data prior to 1998. For those years, we interpolate the spreads to three-month sterling LIBOR rates linearly over each quarter and add them to the monthly LIBOR rates in order to construct monthly time series for retail and wholesale deposit rates.

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