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Francis Breedon, Jagjit S. Chadha and Alex Waters

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Francis Breedon[†] Jagjit S. Chadha[‡] and Alex Waters[§]

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Abstract

After outlining some of the monetary developments associated with Quantitative Easing (QE), we measure the impact of the UK's initial 2009-10 QE Programme on bonds and other assets. First, we use a macro-finance yield curve both to create a counterfactual path for bond yields and to estimate the impact of QE directly. Second, we analyse the impact of individual QE operations on a range of asset prices. We find that QE significantly lowered government bond yields through the portfolio balance channel – by around 50 or so basis points. We also uncover significant effects of individual operations but limited pass through to other assets.

JEL Classifications: E43, E44, E47, E58

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1 Introduction

Following the financial crisis of 2008 Quantitative Easing (QE) - which we define in this paper as large scale purchases of financial assets in return for Central Bank reserves - became a key element of monetary policy for a number of major Central Banks whose interest rates

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[†]Queen Mary, University of London. E-mail: f.breedon@qmul.ac.uk

[‡]University of Kent, Canterbury and Centre for International Macroeconomics and Finance, University of Cambridge. E-mail: jsc@kent.ac.uk.

[§]School of Economics, University of Kent, Canterbury, Kent. E-mail: aw365@kent.ac.uk.

were at, or close to, the zero lower bound. But despite its widespread use, the question of the effectiveness of QE remains highly controversial. Although we now have the benefit of hindsight in the sense that there are a number of QE programmes that can be studied, an empirical assessment of those programmes presents a number of familiar challenges. First, since there is no generally accepted theoretical framework in which to assess QE, empirical studies must either eschew theoretical restrictions that might aid identification or risk having their results dismissed as model-specific[1]. Second, since QE was not entirely unanticipated, in the sense that it was widely discussed by financial market participants before it was implemented, studies that place a large weight on announcement effects may well give misleading results. Third, since QE was implemented in response to an economic crisis, all the standard economic concerns over endogeneity apply in this case. Finally, since the number of QE-policy shocks is still very limited, conventional empirical techniques that rely on a reasonable sample size cannot easily be implemented in this case.

In this paper, which focuses on the impact of the first UK QE programme (March 2009 to February 2010) on asset prices, we aim to control for these problems through two empirical approaches. First we estimate a macro-finance model of the UK government liability curve which allows us to construct a counterfactual estimate of the term structure over the QE period and, under some strong assumptions, to simulate the impact of QE on the yield curve directly. Second, we look in detail at the liquidity effects of the large sample of individual gilt purchase operations and assess the extent to which these liquidity effects extend beyond the gilt market. We also begin with a more qualitative assessment of the impact of QE on UK monetary aggregates following on from a short survey of the theoretical antecedents of QE. This assessment serves as useful background and allows us to link our results from financial markets to monetary quantities such as bank lending.

In the remainder of this section we present a brief review of the literature on empirical assessment of QE. Section 2 then presents an overview of the observed impact of UK QE on monetary aggregates. Section 3 introduces our macro-financial yield curve model and the counterfactual path it generates. Section 4 examines operation-by-operation liquidity effects of QE and Section 5 concludes.

1.1 A Brief Literature Review

Early work on the impact of large scale asset purchases as a tool of monetary policy probably began following ‘Operation Twist’ in the United States in 1961. Although not full Quantitative Easing in the sense of being financed by base money creation, this operation involved

[1] See Chadha and Holly, Eds., (2011) for a treatment of a number of partial equilibrium and general equilibrium modelling approaches that try to understand non-conventional monetary policies. Although there is a growing literature, a workhorse model has not yet been developed.

Federal Reserve purchases of long-term bonds (financed by sales of short-term Treasury Bills) as well as a change in Treasury issuance with the aim of lowering long-term interest rates. Modigliani and Sutch (1966) found that this operation had no significant effect on bond yields, though more recent work by Swanson (2011) has found that this operation had some significant market impact.[2]

More recently, the QE programme implemented by the Bank of Japan from 2001 to 2006 generated new interest in unconventional monetary policy implemented through large scale asset purchases. In a survey of empirical evidence in the Japanese case, Ugai (2007) found mixed evidence. He concluded that the evidence suggested that QE had some signalling impact on market expectations in the sense of confirming that interest rates would remain low for some time, but the evidence on whether the QE operations had any direct effect on bond yields or risk premia was mixed. However, Bernanke *et al* (2004), examining the Japanese experience with QE, found little by way of announcement effects but some evidence from a macro-finance yield curve to suggest that Japanese yields were roughly 50bp lower than expected during QE. Unsurprisingly perhaps, the QE programmes implemented in the aftermath of the 2008 financial crisis have led to a dramatic increase on research in this topic. Most notably, the Federal Reserve's QE programme has spawned a large and rapidly growing literature. Important empirical contributions include Doh (2010), D'Amico and King (2010), Gagnon et al. (2010), Hamilton and Wu (2010), Neely (2010), Hancock and Passmore (2011), Krishnamurthy and Vissing-Jorgenson (2011) and Wright (2011). In the US case, despite a wide range of methodological approaches, there is near-unanimous agreement that the US programme had significant effects on longer-term bond yields though estimates of the scale of the effect vary considerably. For example Gagnon *et al* (2010) find that the $300bn of US bond purchases, which amount to approximately 2% of GDP, resulted in drops of some 90bp in US 10-year Treasuries, while Krisnamurthy and Vissing-Jorgensen (2010) find that a reduction in public debt outstanding of around 20% of GDP would reduce yields by between 61and 115 basis points. So far, the UK's QE programme has attracted less interest. Recently released empirical estimates of the impact of the initial £125bn of QE and then the full £200bn (14% of GDP) on UK gilt yields by Meier (2009) and then Joyce *et al* (2010) suggest that yields are some 40-100bp lower than they would have been in the absence of QE. Caglar *et al* (2011) do, however, suggest that the event study methodology may have overestimated the effects because of the dominant, possibly exaggerated, impact of the first rather than the subsequent six announcements. Thus, in this paper we want to make our expectations of the bond price, in the absence of any QE, conditional on the macroeconomic structure as well as examining the direct impact of actual purchases at each auction.

[2] Both papers did, however, calculate the point response of medium term yields was just under 20bps.

2 Quantitative Easing and the Monetary Aggregates

Tracing the impact of QE on the narrow and broad monetary aggregates serves as a convenient way of describing QE in the UK case and furnishes some useful insights into monetary flows associated with QE. Let us first start with an overview of the theoretical case for QE.

2.1 QE as an open market operation

Generally speaking, quantitative easing is really just an extended open market operation involving the unsterilised swap of central bank money for privately held assets. The key difference is that the duration of the swap is both intended to be long-term and of uncertain length. An open market operation, if unsterilised, leads to an increase in the quantity of base or outside money. This money represents claims on the public sector and will not be neutral with respect to any given expenditure plans if there is a real balance effect that induces a fall interest rates. This is because the increase in money changes the price of claims on the public sector. If, however, the private sector fully discounts the present value of taxes that will need to be paid to meet these obligations then these bonds will not represent net wealth and the operation will be neutral. The debate on the efficacy of such operations hinged on the question of whether the supply of outside money changed the wealth position of the private sector (see Gale, 1982).

But the analysis of such operations lay outside the remit the workhorse New Keynesian (NK) Model in which the evolution of monetary aggregates, which were simply a veil by which real planned transactions were effected, provided no additional feedback to the state of the economy. These models are highly tractable and were used to develop simple, precise policy prescriptions, even at the lower zero bound of Bank rate, by influencing expectations of the duration of any given level of Bank rate in order to induce exchange rate depreciations or positive inflation shocks and so close any given sequence of output gaps in expectation. In these models, open market operations were neutral because at the lower zero bound money and bonds become perfect substitutes and any swap of one for the other does not change the wealth position of the private sector. In fact, in these models QE-type policies are simply forms of commitment strategies that provide signals about the long term intentions of the central bank to hit a given inflation target.

The NK argument that monetary policy can only work through the management of expectations is not a universal result as it relies on particular assumptions. In these models, financial markets are complete in which a representative agent can spring into life and financial wealth is allocated over an infinite life. Idiosyncratic risk in these economies can be hedged and asset prices depend on state-contingent payoffs. In this case, the price of financial assets are not influenced by changes in their net supply, as demand is perfectly elastic.

It seems quite possible though that demand curves for assets, particularly which are issued in large quantities, may become downward sloping, in which case changes in net supply can affect their relative prices. This possibility then means that the relative supply of money or credit can influence market interest rates and so impact directly on expenditure paths without having to rely on pure signalling effects. It is this possibility which gives quantitative easing its influence. And is the main empirical peg on which we run our analysis in Sections 3 and 4, as QE directly alters net supply of debt held by the private sector. Before turning to our direct analysis of bond prices at monthly and then daily frequencies, we analyse the impact of QE on monetary conditions.

2.2 QE and the Bank of England's Balance Sheet

Although a stated policy of quantitative easing was not implemented until March 2009, a number of prior developments paved the way to full easing. Probably the first important step was the dramatic increase in the size of the Bank of England's balance sheet (see, Figure 1), which, occurred in September 2008 following the collapse of Lehman Brothers under the Special Liquidity Scheme. This expansion effectively involved providing liquidity to the UK banking system (temporarily acquiring bank assets in return for liquidity, predominantly through reverse repo transactions) but since it was financed by issuing Treasury Bills it did not result in an equal expansion of the monetary base.

In effect, the monetary base provided through repo transactions was re-absorbed through issuance of other financial liabilities leaving the Bank of England holding risky bank assets financed largely by Treasury Bills. However, it is noteworthy that there was some expansion of the monetary base over this period as banks - which were allowed to set their own targets (within a certain range) for reserve balances held at the Bank of England - chose to set very high targets (close to the limit, ie £1 billion or 2% of their sterling eligible liabilities as set by the Bank of England, whichever was higher) and earn the low but risk-free return that the Bank of England pays on reserves. Thus in some sense a small measure of quantitative easing occurred over this period since some of the increase in the Bank of England's assets was financed by an unusually large expansion of the monetary base. The voluntary increase in reserve balances over this period is also important evidence that banks were willing holders of low-yielding but safe reserve money and so were probably not averse to holding even more reserves when full QE was implemented.

The next step was the policy of 'qualitative' easing that was implemented in January/February 2009 following an exchange of letters between the Treasury and the Bank of England (19 January and 29 January). This involved the creation on January 30th of the Asset Purchase Facility (APF), a legally separate entity run by the Bank of England but with indemnity assurances from the Treasury for any possible losses. Initially, the APF operated by buying unsecured corporate commercial paper financed by issuing Treasury Bills. But following a further exchange of letters between the Bank of England and the Treasury (17 February and 3 March), the Monetary Policy Committee (MPC) meeting of March 5 2009 decided to move to a policy of quantitative easing (QE), with the Bank of England aiming to purchase £75bn of assets through the APF over the following three months, financed entirely by an expansion of the monetary base. Although the APF continued to purchase corporate debt (expanded to include corporate bonds), the vast majority of purchases were of UK government conventional bonds (gilts) with residual maturity of more than 3 years. In order to facilitate the expansion of the monetary base, the Bank of England suspended both the system of targets and limits on banks' reserve holdings and pledged to pay the official interest rate of 0.5% on all bank reserve holdings. The target for asset purchases was then increased to £125 billion at the May 7th MPC meeting, to £175 billion at the August 6th meeting and to £200 billion at the November 5th meeting. At the MPC meeting of 4 February 2010, it was decided not to increase the stock of APF assets any further, and thus QE was effectively temporarily suspended as the programme of asset purchases was by then complete until QE was re-introduced in October 2011. [3].

Figure 2 traces the impact of QE by examining gilt holdings by sector. Prior to the fourth quarter of 2008 the main holders of gilts were UK pension funds and insurance companies, the Overseas Sector and other UK-based non-bank institutions. Following the introduction of QE, the APF quickly became a significant holder of gilts, rising to a peak of about 24 per cent of the total stock (over 13 percent of GDP) by the end of 2009. However, this dramatic increase in APF holdings had remarkably little impact on gilt holdings by other sectors since it was more than offset by an increase in the total stock of gilts in issue. Thus, apart from other UK non-bank institutions (such as households and hedge funds), gilts holding by other sectors continued to rise albeit at a slow rate. Another interesting aspect of the period since late 2008 is the sudden rise in holdings of gilts by banks. This almost certainly reflected increased regulatory pressure on banks to hold more liquid assets.

2.3 QE and the Broader Monetary Aggregates

In the early days of QE, many commentators arguably including the Bank of England itself (see Financial Times, 2010), expected the main indicator of QE success to be more rapid growth in the broad monetary aggregates. In this section we look at the qualitative evidence regarding the impact of QE on broad money and lending, as background to a more detailed look at the policy effect on asset prices.

[3]Following the MPC meeting in October 2011, it was announced on 6 October that a further £75 billion of asset purchases would occur, implying a total stock of £275 billion of such asset purchases.

Overall, broad money (deposit) growth over the QE period was weak. Figure 3 shows both the level of the Bank of England's favoured measure of broad money, M4x (standard M4 less intermediate other financial corporations, or OFCs) and the year-on-year growth rate. Immediately following the introduction of QE, the growth rate of M4x continued to fall, to just under 1% at the end of 2009, and stayed considerably below the Bank's 6-8% target range through 2010. Although this low rate of growth seems at odds with the idea that QE should boost bank lending, there may be a number of explanations. First, without QE, and given the state of demand, there might easily have been even weaker growth, if not a significant contraction of broad money. Secondly, there was a significant level of new debt and equity issuance by the UK banking sector over this period, as it aimed to recapitalise (see Figure 6). Such issuance will tend to reduce M4x growth for a given level of lending in the banking sector, as it increases non-deposit liabilities (so new lending can be funded without increasing deposits). A measure of the downward pressure on the money supply caused by this recapitalisation of UK banks is captured by net non-deposit liabilities[4]. Over the QE period, the cumulative total creation of these liabilities was approximately £242bn, suggesting a substantial undermining of the impact the monetary boost might have had on the money supply.

If we focus on the lending side of banks balances, however, the picture is similar to M4 deposits. Overall total M4 lending excluding securitisations and loan transfers (M4Lx) fell over the QE period by £197.5bn.This reflects an increase in bank holdings of other assets such as central bank reserves (see Figure 1) and gilts (see Figure 2). Breaking down lending by sector, Figure 4 shows that there was some recovery in lending to households over the QE period (reaching around 3% growth at the end of 2009, and continuing into 2010), after a contraction in the 12 months following the collapse of Lehman Brothers. However, lending to Private Non-Financial Companies (PNFCs) showed no such recovery. The largest contraction in lending was in May 2010, with a year-on-year contraction of 4.2% and there was little sign of improvement thereafter.

The low overall rate of money growth is difficult at first blush to reconcile with data from the Bank of England survey on credit conditions. Figure 5 plots the response of corporates to the question "How has the availability of credit provided to the corporate sector overall changed?"[5]. In Figure 5, the blue bars show the response over the past three months, and

[4] The non-deposit liabilities (net) category consists of capital and other non-deposit liabilities of UK banks less their investments in Uk banks and other non-financial assets. In the Bank of England series used (series code LPMVRHV), a negative value indicates an increase in non-deposit liabilities and downward pressure on broad money.

[5] The response of these questions is presented in the Bank of England's Credit Conditions Survey, which is conducted monthly, with the results published quarterly. The survey asks lenders a series of questions to identify trends and developments in credit conditions over the past three months, and to ascertain their expectations for the coming three months. All lending is from UK-based institutions, but it includes both

the red line shows the expectations over the next three months. The expected balance is moved forward one quarter so that expectations can be compared to the actual outturn in the following quarter. Prior to QE, the availability of credit declined, and it did not show much improvement until QE commenced. The survey response is further disaggregated into different factors, and it appears that the key factor driving of the improvement was the changing cost and availability of funds, followed by the increasing availability of loans in the market. Both of these factors, suggest that QE was affecting the loan supply and so the low overall rate of money growth is likely to stem from low levels of demand from deleveraging households and corporations.

In fact it appears that firms' confidence in the availability of funds was expressed in a decision to by-pass the banking system altogether and issue capital directly. Figure 6 shows net capital issuance by PNFCs[6]. This consists of UK-based primary-market issuance of bonds, commercial paper and equity financing in both domestic and foreign currencies by entities domiciled in the UK[7]. Specifically, the majority of assets issued over the QE period by PNFCs were bonds, with shares in second place. The net issuance of commercial paper was generally negative. Although there is considerable heterogeneity across PNFC behaviour that is worthy of further analysis, overall, there is some evidence that PNFCs stepped up their net capital issuance during the QE period, and although this may simply reflect continuing problems with bank financing, the fact that credit conditions were seen to have improved suggests that it may have been motivated by a desire to tap capital markets flush with the proceeds of gilt sales into the QE programme.

To summarise, the period covered by the Bank of England's asset purchase programme can be described as one of low but positive growth in deposits, counteracted by heavy debt and equity issuance in the corporate sector, and to some degree in the financial sector. Overall although monetary aggregates or their counterparties show little improvement over the QE period, suggesting little clear expansion by the banking sector, corporates seemed to have responded to QE by issuing capital directly.

sterling lending and foreign-currency-denominated lending. The survey does not solicit information about capital issuance by the lenders, but asks about available supply and demand conditions. The information here comes from the Bank of England's Credit Conditions Survey for the 3rd Quarter of 2011 Annex 3: Corporate Lending Questionnaire Results.

[6]The data are available in the Bank of England's Bankstats, Table 3.1. There aare also data for building societies (B63M) and resident banks (B32M). The data here go through 2009 only. They are not plotted, but are available on request. The codes for the data in the order presented in Figure 5 are B83I, B79I and B82I.

[7]The bond issued are not part of any specific programme, and represents assets that will have an ongoing series of issues. The commercial paper issued include maturities up to and including one year. The shares consist of both preferred and ordinary shares making up the firm's share capital. Shares can also be bought back for the purpose of being cancelled, or to be held in treasury. Net capital issuance is the difference between issuance and repayments for the three financial instruments.

3 QE and the Yield Curve

As we have seen in the previous section, a fundamental problem in assessing the impact of QE on the monetary sector is to define the appropriate counterfactual. In this section we attempt to estimate such a counterfactual for the nominal gilt yield curve to assess whether yields were significantly influenced by QE. Our approach is to estimate a simple term structure model driven by several macroeconomic factors. This model is then used to estimate a predicted yield curve over the QE period and so the difference between the predicted and actual yield curve over this period can be interpreted as an estimate of the portfolio balance impact of QE, since QE itself is not included as a factor. Of course any macro impact of QE should be reflected in the macro factors that drive our yield curve model, so this exercise can only identify the extent to which large scale purchases shifted the yield curve directly This approach, which is similar to that used by Bernanke, Reinhart and Sack (2004), can be thought of as a sophisticated event study where the market model is our macro term structure model. As well as a counterfactual approach we use some, admittedly ad hoc, assumptions to identify the impact of QE using the estimated parameters of our model, providing an alternative route for estimating the portfolio-balance effect of QE. Both approaches have the advantage of allowing us to estimate the longer term impact of QE, not simply high-frequency announcement effects.

3.1 A Benchmark Term Structure Model

Our macro-finance term structure model is estimated in two-stages. The first stage involves putting the term structure into a the functional form proposed by Svensson (1994). We employ an approach similar to that of Diebold *et al* (2006) and Afonso and Martins (2010), obtaining four latent factors- level, slope and two curvatures- by means of the Kalman filter. The second step is to relate these latent factors to a representative set of macroeconomic variables through a SUR regression.

The functional form proposed by Svensson is:

$$y(\tau) = \beta_1 + \beta_2 \left(\frac{1 - e^{-\tau\lambda_1}}{\tau\lambda_1} \right) + \beta_3 \left(\frac{1 - e^{-\tau\lambda_1}}{\tau\lambda_1} - e^{-\tau\lambda_1} \right) + \beta_4 \left(\frac{1 - e^{-\tau\lambda_2}}{\tau\lambda_2} - e^{-\tau\lambda_2} \right). \quad (1)$$

This factor model approach expresses a large number of yields of various maturities as a function of a few unobserved factors. The yield is denoted as $y(\tau)$ where τ denotes the maturity and β_1, β_2, β_3, β_4, λ_1 and λ_2 are parameters. The parameters λ_1 and λ_2 govern the rate of exponential decay and these values of lambda are fixed prior to estimation.[8]

[8] We solve for the optimal values of β_1, β_2, β_3, β_4, λ_1 and λ_2 using constrained optimisation by minimising

The smaller the value of lambda, the slower the decay and the greater the fit at the longer maturities; the larger the value of lambda the faster the decay and the greater the capacity of the fit at shorter maturities. The lambda is also used to determine the maximum loading of β_3 and β_4. The parameters β_1, β_2, β_3 and β_4 are the parameters which correspond to the appropriate factor loadings. The loading on β_1 is 1. Termed the level, it is constant and can be seen as a long-term factor. Any shift in it will have an equal effect across all yields. The factor loading of β_2 has a functional form that starts at 1 but decays monotonically and quickly to 0. It is considered a short-term factor and is called the slope factor. Any change in β_2 will have a greater affect on the short-term yields than on the longer-term ones, thereby changing the slope of the yield curve. The final two factors β_3 and β_4 have loadings that begin at 0, so they are not short-term. However they increase and then decay back to zero, so they cannot be long-term either. This factor is a medium-term factor and is termed the curvature. Any changes in β_3 and β_4 will have very little effect on either the short or the long end of the yield curve, as the yield curve has very little loading on these maturities. Hence, any increase in these factors will increase medium-term yields and consequently increase the curvature of the yield curve. Therefore, the Svensson representation can now be interpreted as a dynamic latent factor model where β_1, β_2, β_3 and β_4 become time-varying parameters that capture the level (L), slope (S), first curvature factor (C_1) and second curvature factor (C_2) of the yield curve at time t.

As in Diebold *et al* (2006) and Afonso and Martins (2010) we assume that L_t, S_t, $C_{1,t}$ and $C_{2,t}$ follow a first order vector autoregressive process which allows the model to form a state-space system and then using the Kalman filter to obtain maximum-likelihood estimates of the parameters and the implied estimates of L_t, S_t, $C_{1,t}$ and $C_{2,t}$. This estimate is undertaken for the nominal curve and estimation details are available on request.

In order to relate these factors to macroeconomic variables we estimate a SUR model of the following general form:

$$\mathbf{Y}_t=\boldsymbol{\alpha} + \boldsymbol{\rho}\mathbf{Y}_{t-1}+\boldsymbol{\theta}\mathbf{X}_t+\mathbf{d}\boldsymbol{\delta} + \boldsymbol{\varepsilon}_t. \tag{2}$$

$\mathbf{Y}$ is a 4x1 vector of dependent variables (the level, slope and curvature factors identified above), α is the vector of constants ρ is a vector of coefficients for the lagged dependent variables and θ is a matrix of coefficients of the independent variables $\mathbf{X}_t$. The final equations have been determined by a general to specific approach performed simultaneously across all four equations. The analysis of the coefficients and their significance is taken a step further post-estimation. We test exclusion restrictions on each one of the four coefficients from each

the residual sum of squares between the average UK term structure across the entire sample period and the fitted curve from the Svensson methodology. The imposed constraints are λ_1 and λ_2 have to be greater than zero.

equation for each macroeconomic variable and to determine if it could have been excluded from the system (see Table 1). The standard estimator for SUR is feasible generalised least squares (FGLS). We use FGLS as we do not know the true variance-covariance matrix. The SUR estimator using the information in the system of equations is more efficient than an estimator of individual equations. FGLS is preferable to OLS for two reasons, the more correlation there is between the residuals, the greater the efficiency gain attributed to FGLS and secondly, the less correlation there is between the $\mathbf{X}_t$ matrices, the greater the gain to FGLS.

3.1.1 Data

We fit the nominal term structure using 9, 12, 15, 18, 21, 24, 30, 36, 48, 60, 72, 84, 96, 108 and 120 month maturities for the zero coupon forward curve [9] at a monthly frequency between March 1993 and December 2008. The initial set of macroeconomic and financial variables are guided by Clarke and Mortimer-Lee (2008) who analyse the relationship between UK interest rates and key announcements of macroeconomic variables. These are divided into 5 groups, inflation, real activity, policy, foreign and financial and tested down from over 30 variables. For inflation we use inflation expectations which is the average one year ahead inflation forecast from HM Treasury.[10] Real activity is represented by two variables, a real activity index and unemployment. For policy we include the Bank of England's monetary policy interest rate, for our measure of the net supply of bonds we use the debt-to-GDP ratio and to estimate whether maturity of debt issued has a significant impact on yields, we use the ratio of long-term bonds (>15 years residual maturity) to nominal debt outstanding. The demand for bonds may not be perfectly elastic at high levels of debt issuance and so changes in the net supply or the relative supply of longer term bonds may alter their price and affect the shape of the yield curve. Altering the share of long-term bonds in the nominal portfolio increases the average time to maturity of the nominal portfolio.[11] More precise measures of the average maturity and impact of duration of government debt is left to future work. For foreign variables we include the effective exchange rate, German retail sales, the IFO index of business climate, U.S. Non-Farm Payrolls expressed as year on year changes and the Fed Funds Rate. The final group of macroeconomic variables are the financial group

[9] The estimates for the yields are derived from a cubic spline based technique. See Anderson and Sleath (1999).

[10] We refer the reader to 'Forecasts for the UK Economy: a Comparison of Independent Forecasts' for further information.

[11] A change in the relative supply and the maturity of the government debt stock changes the duration of the bond portfolio held by the non-bank financial sector. In the first quarter of 2009 just prior to QE, Other Financial Corporations held 53% of the total portfolio (source: UK Debt Management Office). A large proportion of their gilt holdings will be in long-term bonds as outlined by the UK Pension Act of 1995 stating that pension and insurance companies must hold more long-term debt whose payoffs offset their liabilities. After QE1 they held 42 %.

and for this we use an index of the annual returns of three different equity series and we use a measure of the Libor spread, which is the difference of the three month Libor and the monetary policy rate of the Bank of England. Normally the Libor spread is the difference between the 3 month Libor and Overnight Interest Rate Swaps but as the OIS data does not go back to 1993 we use the policy interest rate as a proxy. Also under the financial group of variables we include a measure of real money[12].

We create an index of real activity using principal component analysis from three different measures of real activity; UK production, UK retail sales and the claimant count. These variables were changed to year on year changes prior to first principal component being extracted. We also create an index of financial returns by taking the annual returns of three different equity series namely, the Standard and Poors index of the 500, the DAX 30 and the FTSE 100. Just like the real activity index we take the first principal component of the three series. We also include time trends.

The descriptive statistics of this model are given in Table 2. The R^2's are high across all four of the equations. Particularly the level and slope equations but the two curvature factors do less well. As found in the other macro-finance literature, we struggle to find a better macroeconomic explanation for the curvature factors. These results are corroborated by analysis of root-mean-squared-errors, with the resulting errors being smaller for the very well explained level and slope. The tests for autocorrelation, heteroscedasticity and normality show that the residuals do not suffer from autocorrelation at one or five percent. Heteroscedasticity is not a problem in the residuals either. The only problem that is apparent is normality. For the level and the second curvature factors we reject that null hypothesis that the errors are normally distributed at both one and five percent We also reject the null hypothesis at five percent for the slope but this is a more satisfactory result. It is only the first curvature factor where we accept the null hypothesis at both one and five percent. ADF tests (not presented) confirm that the forward curve factors are stationary.

3.1.2 Impulse Responses

Figures 7 shows the estimated responses of the nominal forwards to 1% shocks to the final set of variables used to fit the term structure. The dotted lines represent one standard deviation either side. Rather than discuss each impulse response we draw attention to one simple example that a permanent 1% shock to inflation expectations raises nominal forwards by 1% at the ten year horizon. In terms of the possible impact of QE, we find that net public debt

[12] The measure of real money is the Bank of England's notes and coins in circulation (series code LPMAVAB) deflated by RPI. Notes and coins are used to represent narrow money. M0 was the Bank's main narrow money measure. When the Bank introduced its Money Market Reform in May 2006, the Bank ceased publication of M0 and instead began publishing a series for reserve balances to accompany Notes and Coin in circulation. Notes and coins are the longest available measure of narrow money.

to GDP ratio has a small upward impact on forwards of between 3-9 bp for each 1% of debt held as a fraction of GDP: a reduction of debt amounting to just under 25% of GDP might therefore have a effect of some 75 to 225bp on yields (depending on maturity). We also find that the a 1% increase in the fraction of long term bonds outstanding is to increase 5 year yields and beyond by some 13-15bp. We use these results in the simulation below in which we interpret QE as reducing net debt outstanding and also changing the maturity of that debt portfolio.

3.2 An Assessment of QE through a macro term structure model

In this section assess the pure portfolio balance impact of QE using our term structure model (as noted above any macro impact of QE should feed through the macro drivers of our model). We do this in two ways; first we create a dynamic forecast of the yield curve using our macro factors to estimate the impact of QE under the assumption that QE is a key driver of prediction errors over this period (i.e. that QE is responsible for a portfolio balance effect that causes the curve to deviate from its predicted level). Second, through a number of assumptions we identify QE with parameters of the model itself and so undertake a simulation of the impact of QE on the term structure. Both approaches have their drawbacks, but it is somewhat reassuring that they deliver similar estimates.

3.2.1 QE Counterfactual

To construct a counterfactual path for bond yields (i.e. one that does not include the portfolio balance effects of QE), we simply project a path for the term structure using the model described above and actual outturns for the macro variables as the only inputs. Our projection starts in January 2009 and continues over the whole QE period. The 1,5 and 10 fitted forward rates and forecast errors are shown in Figure 8. We find in general the model *overpredicts* the actual forward curves observed from around March onwards at horizons longer than around 24 months. This overprediction averages 67bp at the 5 year maturity and 46bp at the 10 year over the period in which QE operated. [13] This result is consistent with a QE portfolio balance effect in timing, direction and duration (in the sense that only yields above 2 year maturity seem effected, yields are lower than predicted and the overprediction starts at the same time as QE was announced and implemented). There is also little evidence of a pre-announcement effect in the sense that the fall in bond yields seems

[13] A second forecast was performed from January 2007 to January 2010 to test the robustness of the forecast. The model was re-estimated from March 1993 to December 2006. We compare the dynamic factors of both model specifications from January 2009 to January 2010 using a Diebold-Mariano test. The average forecast errors are presented in Table 3. We test the forecast errors from each sample under the null hypothesis that the forecast error of one model minus the forecast error of the second model is equal to zero. We find that we do not reject the null hypothesis for any of the four factors. Details available upon request.

to occur in March when the programme was announced. In fact, in the two months prior to the QE operations, the model *underpredicts* the medium to long end of the term structure by some 45 bp on average at 5 years and 80bp at 10 year horizon.[14] One explanation for this underprediction before QE may be that their were heightened concerns over UK solvency over those two months. Thus, although our model includes the debt-to-GDP ratio as a factor this is unlikely to capture these solvency concerns for reasons we discuss below.

It is likely that the two financial variables, the exchange rate and the Libor spread are likely to contain immediate indirect effects from Quantitative Easing. Quantitative Easing causes a depreciation in the exchange rate which leads to an increase in yields whereas the improvement in liquidity and an increase in market sentiment should cause the Libor spread to fall putting downward pressure on the yield curve. These two indirect effects project opposing forces on the yield curve. In Table 3 we include the average forecast error in basis points for three different regressions, the first excludes the Libor spread and we find that there is still a considerable over prediction at five year forward and the ten year forward of 63 and 35 basis points respectively. The second regression excludes the Exchange rate and we find that there is still an overprediction of 27 basis points at 5 years but at ten years there is a slight underprediction suggesting strong downward pressure the UK curve from the improvement in the money market. The final specification which excludes both the Libor Spread and the exchange rate produces a forecast that still overpredicts the actual curve by approximately 20 basis points at both the five and ten year forward.

Figure 9 shows the behaviour of UK Government Credit Default Swaps (CDS) over this period. It shows that there was indeed a large spike up in perceived default risk just prior to QE and a significant decline as QE was implemented. If we adjust bond yields for this CDS effect we find that the model underprediction in January and February is more than explained by this credit risk effect, and indeed some - though not all - of the fall in yields that occurred subsequently was associated with reduced credit risk. Of course one might reasonably argue that QE was the cause of the fall in perceived credit risk that occurred around March 2009, though we cannot test this proposition using our model.

3.2.2 QE Simulation

Although our counterfactual path gives an intuitively appealing estimate of the QE effect, it is hardly definitive. Firstly the difference between the actual and predicted path of forward rates is not statistically significant according to our standard errors. Second, one might reasonably argue that so much was going on over this period that the difference between the two paths could be explained by any number of factors not captured in our model not

[14] The forecast errors and standard deviations by maturity for each month of Quantitative Easing is available upon request.

just QE. Thus in this section we take a different approach to estimating the QE effect, by simulating the estimated effect of QE using the estimated parameters of our model.

In order to do so we need to make a number of assumptions that allows us to proxy QE by factors that drive our model.

1) We assume that the variable debt-to-GDP captures a pure supply effect on the yield curve and not other factors like credit risk (i.e. the high debt-to-GDP increases the perceived likelihood of default). This assumption can be partially justified by observing that perceived credit risk was insignificant over almost all of the estimation period of the model (apart from the last few months).[15]

2) Given our first assumption, we then assume that a reduction in the supply of gilts available to the private sector through QE has the same impact as an equivalent reduction in the overall debt-to-GDP ratio. These two assumptions then mean we can interpret the overall impact of QE as a reduction in the debt-to-GDP ratio.

3) In a similar way, we assume that our maturity variable captures a pure supply effect on long maturing debt, and so it can be used to capture the impact of a change in the average a maturity of debt available to the private sector due to the pattern of purchases associated with QE.

4) Finally, we make the assumption that the reduced debt-to-GDP effect of QE occurs when details of the amount to be purchased was announced, whilst the maturity effect occurs when debt purchases were implemented (since market participants would not know the precise maturity breakdown of QE purchases until a few weeks before they were implemented).

Given these assumptions we can create a direct estimate of the impact of QE on bond yields as the combination of the total reduction in the supply of gilts available to the private sector and the change in the maturity of the debt portfolio of the remaining gilts due to QE. As noted above we assume the debt-to-GDP effects occurs when the amount to be purchased was announced at each MPC meeting (£75bn in March, £50bn in May, £50bn in August and £25bn in November) Following the March announcement and the amount of purchases led to a fall of 5.35% of debt-to-GDP and at the end of the QE purchases it amounted to 14% of GDP.

To calculate the maturity effect on the debt portfolio we use the estimated maturity parameter from our yield curve model. This can be seen in the impulse response shown in Figure 7 which is based on the share of long-dated gilts (>15 years residual maturity) relative to the total stock of nominal bonds outstanding. To calculate the effect that QE had on the maturity of the nominal debt portfolio we determine the amount of long bonds and the total amount of nominal bonds outstanding. We calculate the notional amount of long-term

[15] The CDS data used in this analysis for UK government liabilities does not cover the entire estimation sample so we cannot condition our supply effects on changes in credit risk.

bonds purchased in the reverse auctions each month (and the cumulative amounts thereafter) and subtract this from the total amount of long-term bonds outstanding each month. We then divide this amount by the total portfolio of nominal bonds outstanding minus total QE purchases across all maturities. The difference between the two series (long-term bonds as a share of the total nominal portfolio outstanding after adjusting for QE purchases) shows that the maturity of debt according to our measure actually rose (as would the duration of the portfolio) initially as a result of QE, since QE operations were initially focussed on bonds of 5 to 15 year residual maturity but also the government were issuing a larger proportion of longer-term debt over the same period, so the share of long-term bonds in the nominal portfolio were infact increasing. However, around July 2009 purchases of long-dated bonds increased significantly so that the maturity of outstanding debt portfolio began to fall (see Figure 1). This pattern means that for much of the QE period the maturity effect actually led to higher not lower longer term yields.

Table 4 shows these effects in detail for 5 and 10 year forward rates. It shows how the debt-to-GDP effect of QE rises steadily over the period as the amounts to be purchased increased. The maturity effect initially offset the debt-to-GDP effect somewhat as the average maturity of remaining debt rose somewhat and then fell again. It is interesting to compare the predicted QE effect from our simulation with the prediction errors described in the previous sub-section. Over the whole QE period, the average QE effect predicted by our simulation was to reduce 5 year forward rates by 63 basis points, whilst the model overprediction was 67bp on average. The same figures for 10 year forwards were 87bp and 45bp respectively. Similarly the peak impact of QE according to our simulation was 111bp and 136bp for 5 and 10 year forward respectively whilst the peak model overprediction was 110bp and 99bp for the same maturities. Thus the two approaches give reassuringly similar results.

Although we feel it is beyond the scope of this paper we do examine some possible spillover effects from the Federal Reserve regarding its own purchases of US. Treasury Notes and Bonds because of the timing of the US purchases and those of the UK coincide. Using different transformations of US forward data[16], for example, monthly differences or a measure of the slope (defined as the two year rate minus the ten year rate). We estimate the impacts that US yields may have on the UK curve using a constrained linear regression, fixing the coefficients of our initial specification. As a stylised fact, the correlation between the US and UK ten year forwards is 77% and we find that the US curve has a statistically significant impact on the UK curve. This then suggests that we can estimate spillover effects from US Quantitative Easing.

[16] This data can be found at: http://www.federalreserve.gov/econresdata/researchdata.htm
This is based on the methodolgy of Gürkaynak, Sack and Wright (2006). They use the Svensson methodology to fit the US treasury curve to retrieve the implied forwards.

We adopt the same announcement effect methodology of Gagnon *et al* (2010) where we examine both the one day and the two day change which is measured from the close of business the day before the Fed announcement and the close of business on the day of the announcement or the day after the announcement. There were 8 Federal Open Market Committee statements that were made over the course of the UK Quantitative Easing programme.[17] The impact on the US forwards vary depending on maturity and the size of the announcement window. Examining the cumulative change on the US two, five and ten year forwards we find that the two year falls by as much as 37 basis points over the one day window and 87 basis points over the 2 day window. The five year forward declines by 37 and 78 basis points over the one day and the two day window respectively and the ten year forward rises by 1 basis point over the one day window but falls 29 basis points over the two day window. This suggests that it may have taken the market some time to understand and absorb all of the information.

In the same manner in which we calculate the impact of the portfolio balance effect and the maturity effects, we condition the size of the impact that these announcements may have had on the UK curve with the estimated impact from the US curve. Depending on the data transformation used the size of the US spillover effects vary. Using the calculated announcement effects over the two day window and taking the estimates of the one month difference of the US ten year rate, the UK curve could have fallen by as much as 92 basis points at the ten year forward and the five year forward could have been reduced by 57 basis points. The estimated impact on the US slope, the fall of the ten year rate relative to the two year rate and using the two day window announcement effect we find that the UK five year rate can fall by as much as 26 basis points and the ten year forward by as much a 13 basis points. Depending on the transformation used, the impact on the UK curve can indeed of a considerable size. However, unlike the debt and maturity effects which are believed to by permanent up until the point where QE is reversed, the announcement effects are believed to be only transitory and dissipate when further news enters the market.

4 Liquidity Effects of Individual Operations

Having estimated the long run effect of the whole QE programme on the yield curve, in this section we turn our attention to higher frequency (daily) estimates of the impact of individual QE operations Looking at individual QE operations has two significant advantages over the identification of the overall QE effect described above. First, the sample of operations is large and so standard statistical techniques have some power. Second, these operations

[17] The 2009 announcements were made on the 18^{th} March, 29^{th} April, 24^{th} June, 12^{th} August, 23^{rd} September, 4^{th} November, 16^{th} December and one statement in 2010 on the 27^{th} January.

were, of course, entirely anticipated and so any effect we find is entirely due to liquidity. In this section we look at the market impact of these operations to assess the extent to which they produced a pure liquidity effect on the gilt market and other markets. This not only allows us to confirm that QE did indeed influence the bond market, but also gives us an opportunity to test whether QE influenced other asset prices. Of course, it is entirely possible that the entire market impact of QE occurs through announcement effects rather than through its actual implementation as market participants may well position themselves so as to be prepared to absorb the pre-announced market operation. In fact, some studies such as Beneish and Whaley (1996) and Hau, Massa and Peress (2010) in the case of S&P and MSCI-Global index changes respectively found price reversals at implementation date so that the market impact of an announcement is reversed at implementation (as implied in the market maxim "buy the rumour, sell the fact"). However, in our case we do indeed find a significant market impact whereby bond prices rise before each QE operation and then fall back subsequently as might be expected if liquidity effects are important.

To estimate the size of the liquidity effect of QE operations we conduct a simple event study. This involves looking at the average price movements around all QE operation to see if there is a common pattern Overall, whilst there are 576 individual bond purchase operations in our sample, but these operations tended to be grouped together on a single day with the actual gilts eligible for each operation being announced the previous week (though market participants would have been able to make a well-educated guess of which gilts would be eligible by looking at previous operations). In practice, we treat a group of operations on a single day as a single operation giving us a sample of 92 events (taking the average impact across all the gilts purchased in the operation occurring on a particular day). We then looked at daily movements in bond prices using end-of-day midquote data supplied by the UK Debt Management Office around these QE operations. We use prices rather than yields in this analysis as they form a natural starting point from which to look at other assets such as equities and the exchange rate (though the same analysis based on yields give very similar results).

In the analysis presented in Table 5, which focusses purely on bonds eligible for the relevant operation we undertake our event study using two different approaches First, in the 'no change' scenerio we simply present the average pattern of bond prices around QE operations relative to the price received at the operation itself. Thus, for example, when table 5 shows that the t+15 price is -0.85, this means that on average the price of bonds eligible for QE operations were 0.85 percent 15 days after the operation than they were at the time of the operation itself. We call this the 'no change' scenerio since it implicitly assumes that in the absence of a QE operation bond prices would have been unchanged over the event window. Second, in the 'interpolated model' scenerio we construct a counterfactual daily path for bond prices based on a linearly interpolated prediction from the yield curve model described above, we then judge price movments relative to that counterfactual path. So, for example, when Table 5 shows that the t+15 price is -0.67, this indicates that 15 days after the QE operation bond prices are 0.67 percent below the operation price after adjusting for the predicted price movement from our interpolated model (i.e. our model predicts that in the absence of a QE operation the average bond price would have been 0.18 percent lower). This adjustment is analogous to the use of a market model like the CAPM used in stock market event studies and effectively helps control for any trend in prices over the event window that are due to underlying macroeconomic developments.

Table 5 summarise the results of these event studies. It shows a significant operation day effect (column t) whereby the price accepted at the QE operation is over 0.1 percent higher than the average price at the end of the operation day. Looking at model 2 in particular, there also seems to be a steady upward move in price in the 15 days before the operation followed by an offsetting decline in the 15 days after the operation with prices rising about 0.6 percent in the run up to the operation (relative to the price accepted in the operation) and then falling about 0.6 percent subsequently (also shown in Figure 10). At first sight, the length of time over which this price effect occurs may seem surprisingly long. However, given the relatively low level of turnover in non-benchmark bonds and the opacity of pricing in the gilt market (see for example Nath (2004)) slow price responses are often observed in this market. In particular, the pattern we observe here is very similar (though of opposite sign because we look at purchases rather than sales) to the path of bond prices in the period around a bond auction (see Ahmad and Steeley (2007)). Interestingly, the slow response pattern also supports that argument of Martin and Milas (2012) in this volume, that QE event studies based on short windows like one or two days are unlikely to capture the impact of QE correctly

As well as the key analysis presented in Table 5 and Figure 10 we undertook some robustness checks of our QE results. First, as noted above, although we present the results for bond prices we also conducted the analysis for bond yields. This distinction could be important since the average duration of bonds purchased in QE operations varied considerably (ranging from an average per operation of about 4 years to 20 years) Although the results were similar for yields, it is notable and perhaps unsurprising that the price effect of operations tend to be higher for long duration bonds but that the yield effect tended to be smaller. Given the heteroscedasticity in both price and yield responses to QE operations we also test for the significance of these liquidity effects using a non-parametric Wilcoxon test. These show that when using the average price accepted in the operation as a benchmark, these liquidity effects are highly significant - particularly in the period after the operation. However, relative to the price at the end of the operation day, the effects are somewhat less significant - and though significance at conventional levels occurs at a number of horizons it does not occur as consistently. As well as looking for duration effects we also checked to see if larger operations had a bigger price impact (operations ranged in size from about 1.3 billion to 5 billion pounds).. We did indeed find some tendency for larger operations to have a bigger price impact, though the relationship was not significant. Finally, we looked at the time profile of the price effect to see if the market reponse changed as participants became more familar with QE operations. Overall we found that there was no discernable change in the price impact of operations over time

Since Table 5 shows a generally significant liquidity effect on gilts selected for QE operations it is interesting to see whether this effect is also observable in other bonds and indeed in other asset prices. Bearing in mind a large number of caveats (not least that liquidity effects may not influence other asset prices in the same way as the overall impact of QE) such an exercise does perhaps give us some insight into the extent to which QE influences financial markets in general rather than just government bonds. Table 6 shows the behaviour of the rest of the government bond market (based on average prices of bonds in each maturity range as calculated by the Financial Times) and other asset prices around these operations. In all cases the table compares prices at various time horizons with prices at the end of a QE operation date. Starting with the gilt market it shows that, apart from the 0 to 5 year sector, QE operations seem to have an impact on the average price of bonds (including those not purchased in the QE operation) in the sense that there are significant price different relative to the day of a QE operation in at least one time horizon. This impact seems to carry through to both 10 year corporate bonds (both AA and BBB) and Swaps where the price impact of these operations are comparable with that on the 10 year sector of the gilt market. The impact on 10 year OIS is weaker, but this probably relates to the low liquidity of such a long-dated overnight interest rate swap. Moving onto the exchange rate and equity prices however there seems to be little discernible QE effect. In the case of the equity market this result seems to suggest that the reduction in duration risk associated with QE did not feed through to other long duration assets like equity. Overall, these results suggest that the liquidity effect of QE was felt across the whole bond market, but did not spread beyond that market. However, such a conclusion is clearly tentative.

5 Conclusion

Quantitative easing has become an important tool of monetary policy in many countries over recent years, but its effectiveness is still open to considerable doubt. In this study we have taken several approaches to assessing its financial market impact and in all cases have found a significant and economically important impact of QE on the bond market. In fact, along with the growing body of evidence for the US it seems that our evidence is contributing to a growing consensus that QE is indeed effective in terms of influencing longer term bond yields through a portfolio balance effect with an impact of around 50bp at ten years with the most likely range being something like 30-90bp. However, the broader impact of QE, on other assets and on the economy in general remains controversial as our qualitative description of the impact of QE of monetary aggregates confirms. Certainly, that fact that QE has been implemented during a credit crunch - a period when even conventional monetary policy has uncertain effects - probably means that this broader question is likely to remain unresolved for some time.

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Tables

Table 1. Exclusion restrictions tests on the estimated term structure model

Exclusion restrictions within equations	
Level	5798.85 [0.0000]**
Slope	5462.55 [0.0000]**
Curv. 1	1628.32 [0.0000]**
Curv. 2	772.02 [0.0000]**
Exclusion restrictions across equations	
Inf. Exp.	10.27 [0.0059]**
Real Activity	12.75 [0.0004]**
BoE Policy Rate	68.67 [0.0000]**
Debt to GDP	10.33 [0.0013]**
UK Eff. ER	32.84 [0.0000]**
IFO	12.59 [0.0004]**
German Retail Sales	28.34 [0.0000]**
$\left(\frac{M}{P}\right)$	19.80 [0.0000]**
Libor	19.71 [0.0000]**
Maturity	4.96 [0.0259]*

Note: This table presents tests for the exclusion of variables within and across equations and only includes those variables used in the final specification. All tests are a Chi^2 with four degrees of freedom.

Table 2. Descriptive Statistics for estimated Term Structure Model

	Factor			
	Level	Slope	Curv.1	Curv.2
R^2	0.950	0.954	0.863	0.725
RMSE	0.490	0.531	1.141	1.866
Durbin-Alt	0.020 [0.8865]	0.307 [0.5798]	0.760 [0.3834]	4.835 [0.0279]*
Breusch-Pagan	2.98 [0.0844]	1.63 [0.2018]	1.48 [0.2238]	6.56 [0.0104]*
Normality	19.085 [0.0000]**	6.2886 [0.0162]*	0.62410 [0.7319]	39.278 [0.0000]**

Note: The Durbin-Alternative test (with one lag), with the null hypothesis that the errors are homoscedastic, with one degree of freedom. The Breusch-Pagan test has 1 degree of freedom and the null hypothesis is no autocorrelation, this test also has one degree of freedom. The normality test has two degrees of freedom and the null hypothesis is that the errors are normally distributed. All tests have a Chi^2 distribution and ** represents rejection of null at the 1% level and * represents rejection of the null at the 5% level.

Table 3. Average Forecast Error Over the QE Period from Various Model Specifications.

Model Specification	5 Year Forward	10 Year Forward
Benchmark	−67 (92)	−46 (71)
Forecast from 2007	−37 (306)	−31 (272)
Ex. Libor	−63 (88)	−35 (69)
Ex. ER	−27 (84)	2 (63)
Ex. Libor & ER	−20 (84)	−19 (65)

Note: The average forecast errors are in basis points and in parenthesis are the standard errors. The benchmark model is the same as that used in Section 3.2.1 and for the analysis 3.22. The model from 2007 is the forecast used in the Diebold-Mariano test in Section 3.2.1 that is used to test the robustness of the forecasts. The models that exclude the fast-moving variables are estimated from March 1993 to December 2008 and the model is forecasted over the same period as the benchmark model.

Table 4. Estimates of the Impact of QE on 5 and 10 year Forward Rates (in basis points)

	5-Year Forward				10-Year Forward			
	Counterfactual	Simulation.			Counterfactual	Simulation		
	Prediction error	Debt effect	Maturity effect	Total.	Prediction error	Debt effect	Maturity effect	Total
Feb '09	35	0	0	0	104	0	0	0
Mar '09	-99	-37	3	-34	-50	-48	2	-46
Apr '09	-47	-37	14	-23	-7	-48	11	-37
May '09	-18	-62	21	-41	50	-80	16	-64
Jun '09	-54	-62	27	-35	-35	-80	21	-59
Jul'09	-38	-62	35	-27	-47	-80	27	-53
Aug '09	-75	-87	26	-61	-70	-112	20	-92
Sept '09	-110	-87	7	-80	-99	-112	6	-106
Oct '09	-65	-87	0	-87	-57	-112	0	-112
Nov '09	-91	-98	4	-94	-87	-126	3	-123
Dec '09	-67	-98	2	-96	-50	-126	2	-124
Jan '10	-73	-98	-13	-111	-54	-126	-10	-136

Table 5. Bond prices around QE operations

	t-15	t-10	t-5	t	t+1	t+5	t+10	t+15	t+20
Model 1: 'No Change'									
Relative to operation price	-0.38	-0.32	-0.21	-0.12	-0.21	-0.43	-0.63	-0.85	-0.84
	[0.33]	[0.09]	[0.12]	[0.01]	[0.09]	[0.03]	[0.00]	[0.00]	[0.00]
Relative to end-day price	-0.26	-0.20	-0.09		-0.08	-0.31	-0.51	-0.73	-0.71
	[0.39]	[0.26]	[0.26]		[0.27]	[0.09]	[0.06]	[0.01]	[0.00]
Model 2: Interpolated Model									
Relative to operation price	-0.56	-0.44	-0.27	-0.12	-0.20	-0.37	-0.51	-0.67	-0.60
	[0.14]	[0.06]	[0.04]	[0.01]	[0.09]	[0.06]	[0.00]	[0.01]	[0.01]
Relative to end-day price	-0.44	-0.33	-0.15		-0.08	-0.25	-0.39	-0.55	-0.48
	[0.20]	[0.12]	[0.21]		[0.27]	[0.14]	[0.06]	[0.14]	[0.03]

Note: The table presents average price differential in percent between either the average price accepted in the QE operation or the price at the end of the operation day and the price at various horizons. In the case of model 2 the price differential is adjusted for the predicted movement in prices from an interpolated version of the yield curve model described above. Figure in square brackets is the probability that the price differential is zero based on the two-sided Wilcoxon Rank Test.

Table 6. Asset Price Movements Around QE operations

	t-15	t-10	t-5	t+1	t+5	t+10	t+15	t+20
APF Gilts	-0.44	-0.33	-0.15	-0.08	-0.25	-0.39	-0.55	-0.48
	[0.20]	[0.12]	[0.21]	[0.27]	[0.14]	[0.06]	[0.14]	[0.03]
Gilts 0-5 years	-0.19	-0.12	-0.07	-0.01	0.04	0.08	0.12	0.19
	[0.21]	[0.33]	[0.21]	[0.39]	[0.79]	[0.46]	[0.61]	[0.54]
Gilts 5-10 years	-0.24	-0.15	-0.08	-0.04	-0.07	-0.17	-0.22	-0.20
	[0.12]	[0.79]	[0.39]	[0.06]	[0.12]	[0.00]	[0.12]	[0.03]
Gilts 10-15 years	-0.25	-0.16	-0.10	-0.05	-0.10	-0.26	-0.36	-0.36
	[0.09]	[0.61]	[0.39]	[0.21]	[0.16]	[0.02]	[0.09]	[0.01]
Gilts 15-25 years	-0.58	-0.35	-0.18	-0.06	-0.18	-0.43	-0.53	-0.52
	[0.26]	[0.61]	[0.12]	[0.54]	[0.39]	[0.01]	[0.03]	[0.04]
Gilts 25 years+	-0.58	-0.38	-0.25	-0.06	-0.07	-0.26	-0.24	-0.18
	[0.04]	[0.03]	[0.12]	[0.54]	[0.67]	[0.39]	[0.21]	[0.39]
Effective Exchange Rate	-0.01	-0.04	-0.03	0.01	0.07	0.13	0.27	0.18
	[0.39]	[0.26]	[0.21]	[0.39]	[0.67]	[0.74]	[0.88]	[0.79]
FTSE 100	-0.02	-0.01	-0.01	0.00	0.01	0.01	0.03	0.03
	[0.09]	[0.26]	[0.26]	[0.88]	[0.39]	[0.67]	[0.74]	[0.79]
10 year AAA bonds	-0.09	-0.06	-0.05	0.01	0.01	-0.02	-0.04	-0.05
	[0.33]	[0.39]	[0.26]	[0.33]	[0.33]	[0.04]	[0.06]	[0.01]
10 year BBB bonds	-0.13	-0.09	-0.07	-0.00	-0.05	-0.06	-0.09	-0.15
	[0.33]	[0.54]	[0.06]	[0.26]	[0.91]	[0.04]	[0.09]	[0.33]
10 year Swap	-0.03	-0.01	-0.01	-0.01	-0.02	-0.05	-0.08	-0.07
	[0.02]	[0.33]	[0.21]	[0.26]	[0.39]	[0.06]	[0.46]	[0.21]
10 Year OIS	0.00	0.02	-0.00	-0.01	-0.3	-0.07	-0.11	-0.11
	[0.16]	[0.46]	[0.61]	[0.67]	[0.21]	[0.06]	[0.21]	[0.12]

Note: The table presents average price differential, in percent, between price at end of day of QE operation and price at various horizons. In all cases the asset price is adjusted for any trend over the sample, in most cases through a simple linear trend adjustment, but for APF gilts using tour yield curve model, so the first row reproduces the results of the final two rows of Table 5 Figure in square brackets is the probability that the price differential is zero based on the two-sided Wilcoxon Rank Test. OIS data courtesy of the Bank of England.

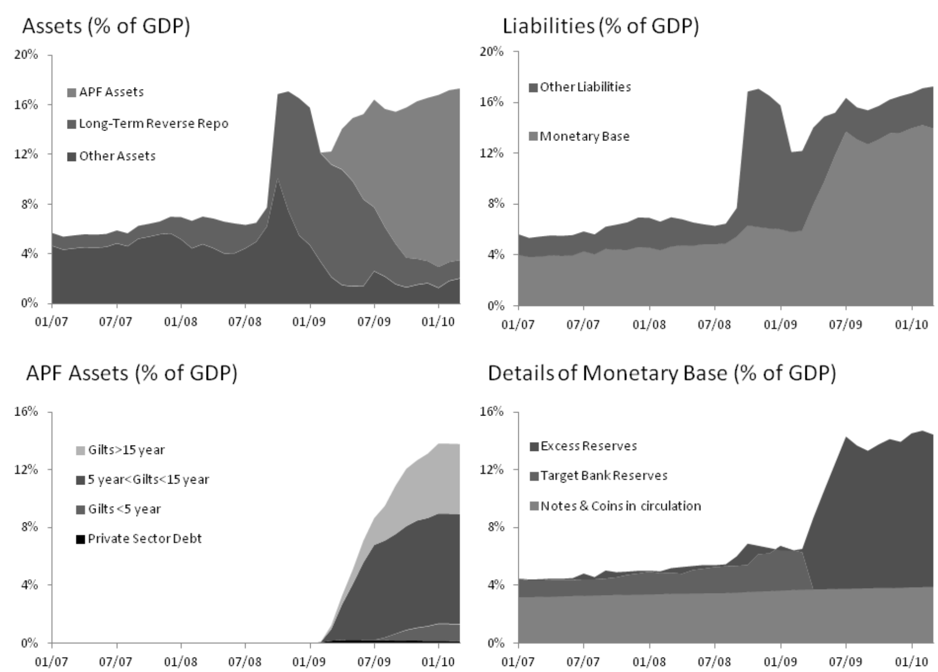

Figure 1. Bank of England's Balance Sheet

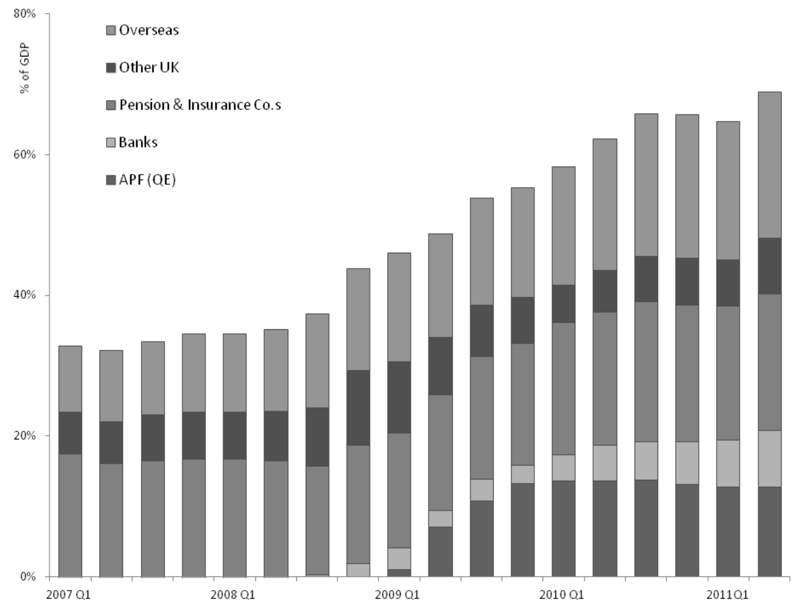

Figure 2. Gilt Holdings by Sector as a Fraction of GDP

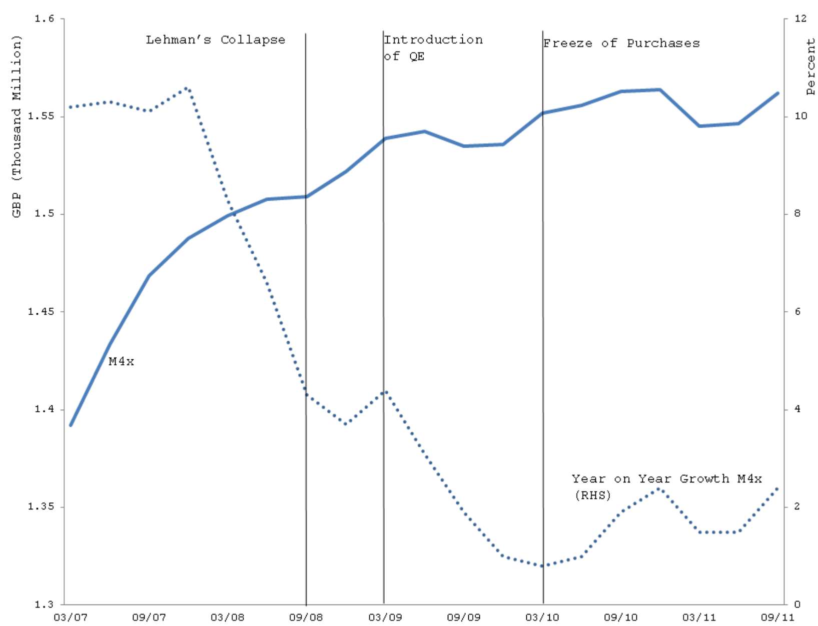

Figure 3. M4x and Year on Year Growth of M4x

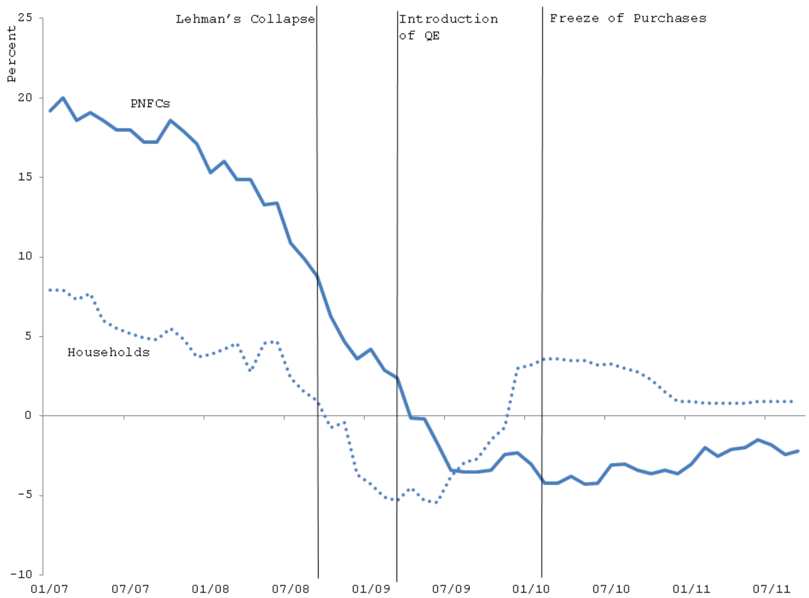

Figure 4. Year on Year Growth in Total M4x Lending to Households and to PNFCs

Figure 5. The Availability of Corporate Credit

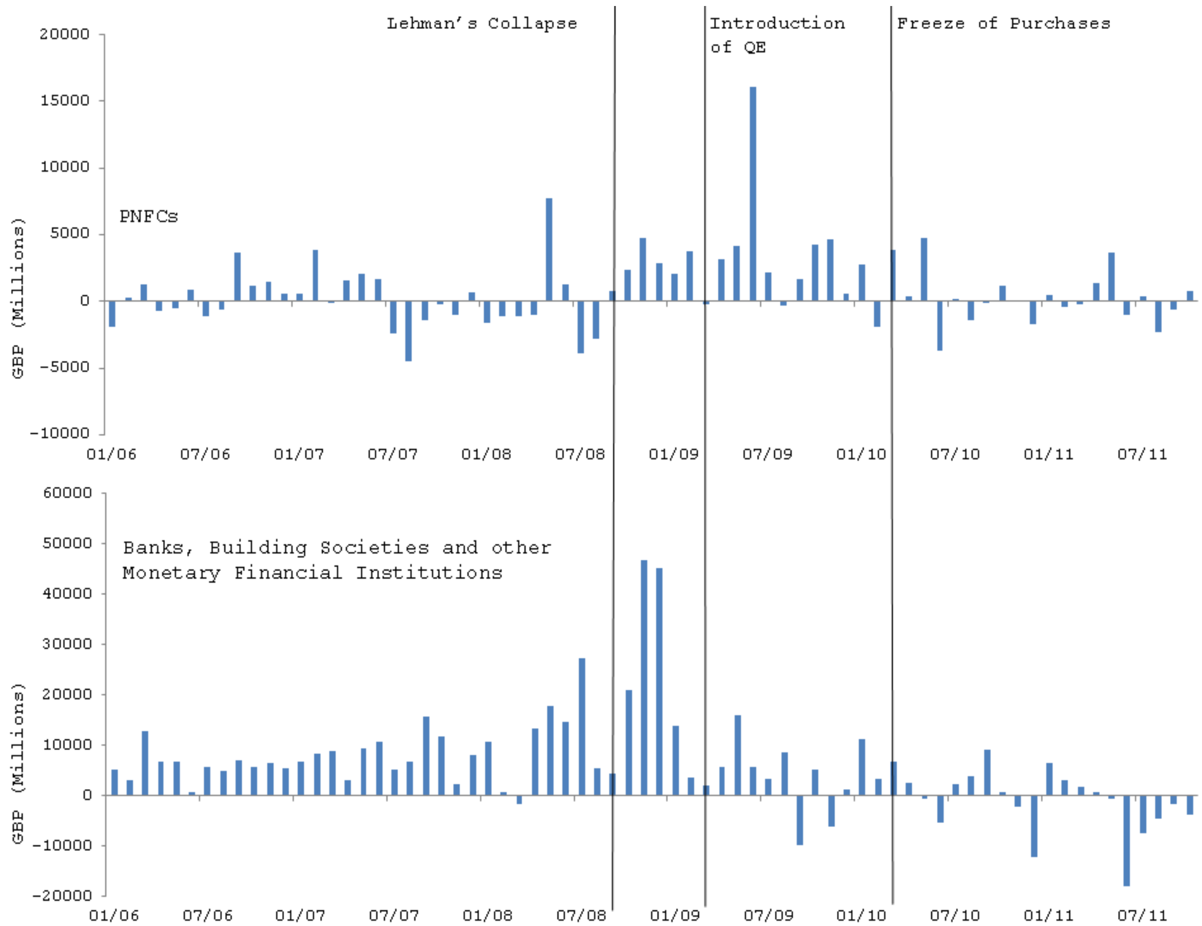

Figure 6. Monthly Net Capital Issuance by Sector

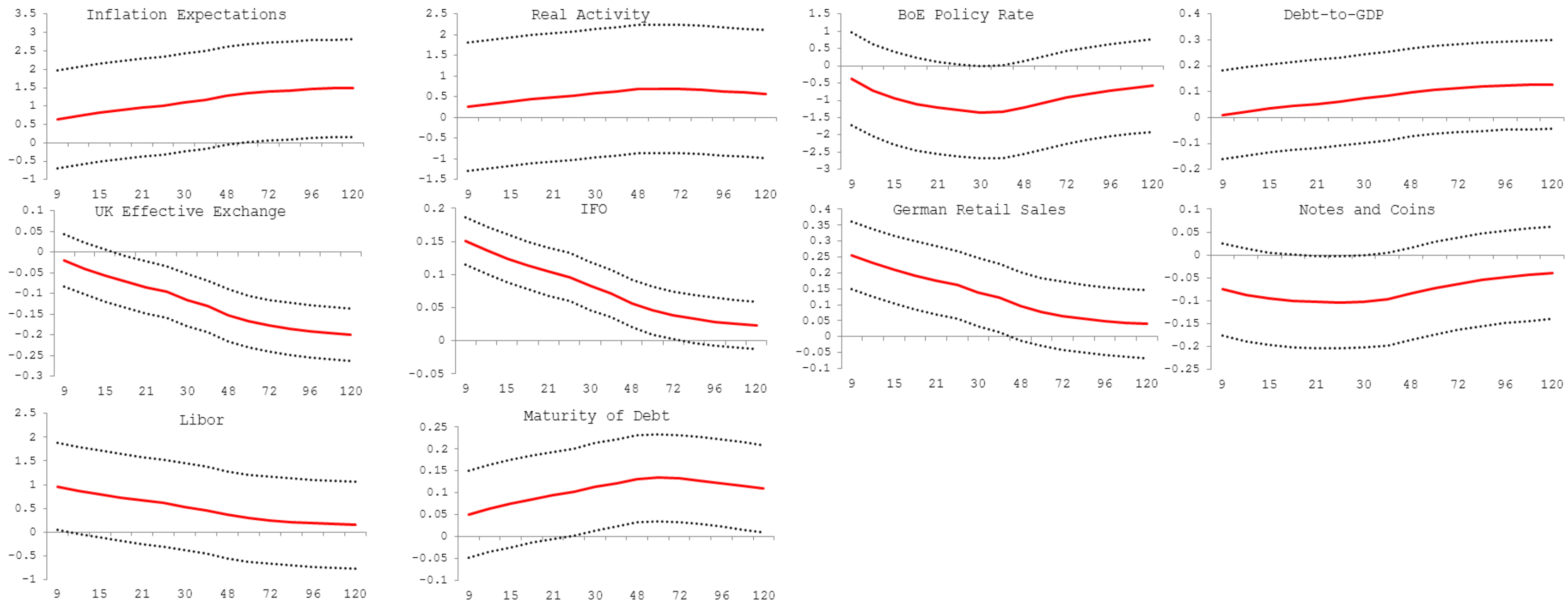

Figure 7. Impulse Responses of Forward Curve to 1% shock in Macro-Factors

Note: In Section 3.1.2 we use the examples of a 1% increase in inflation expectations or an increase in public net debt relative to GDP by 1%. To help the reader gauge the size of the impacts relative to the variability of the factors, we list one standard deviation of each macroeconomic and financial variable over the estimation period. Inflation expectations, 0.49%. Real activity, 1.38%. The Bank of England policy rate has a standard deviation of 1.52% but over the estimation sample, whenever the Monetary Policy committee change the policy rate, it is often in increments of 25 basis points. Public net debt relative to GDP is 6.78%. UK effective exchange rate, 8.02 index points. IFO business climate index, 5.83 idnex points. German retail sales, 2.09%. Real notes and coins, £6.67 billion. Maturity effects of debt, 7%.

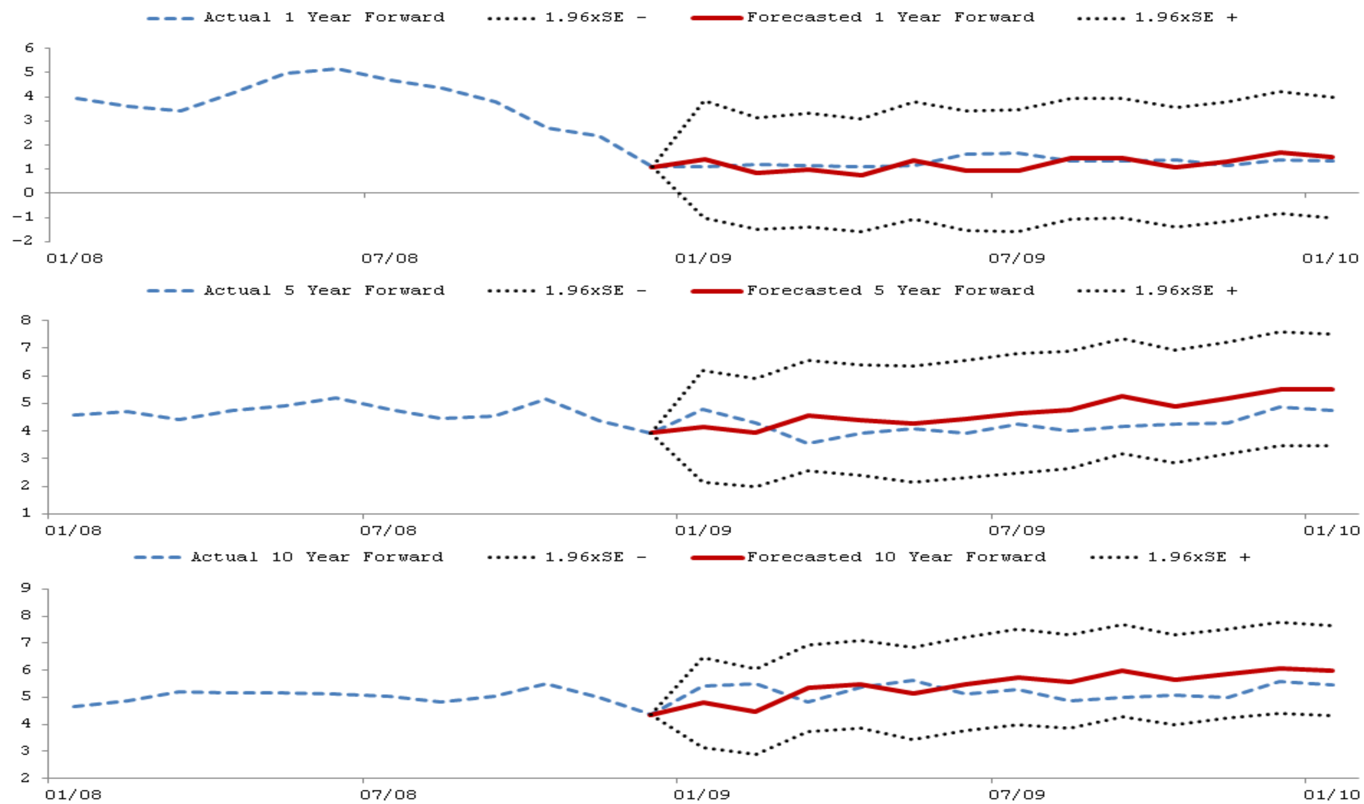

Figure 8. 1, 5 and 10 Year Actual and Forecast Forward Rates

Note: Figure 8 presents the actual forwards from January 2008 up until January 2010. We also include the forecast and the forecast interval (95% confidence). To construct the forecast interval for each forward (1, 5 and 10 years) we take the forecasted factors from the SUR regression and multiply these estimated factors by the appropriate factor weighting for each maturity from the Svensson methodology across each of the forecast periods. We then construct a joint forecast error from each of the different factors for each forecast observation, also multiplying the forecast error by each factor weight so it is scaled accordingly.

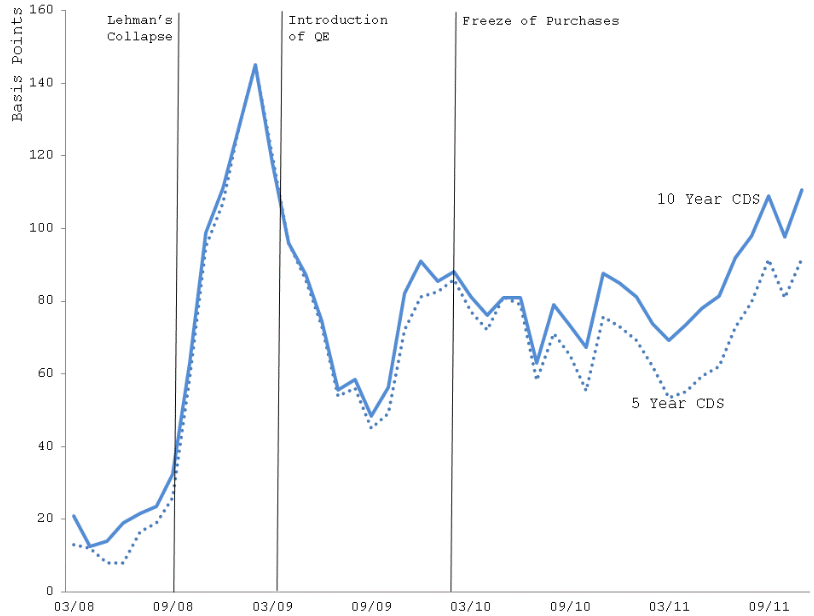

Figure 9. 5 and 10 Year UK Government Debt Credit Default Swap Spreads

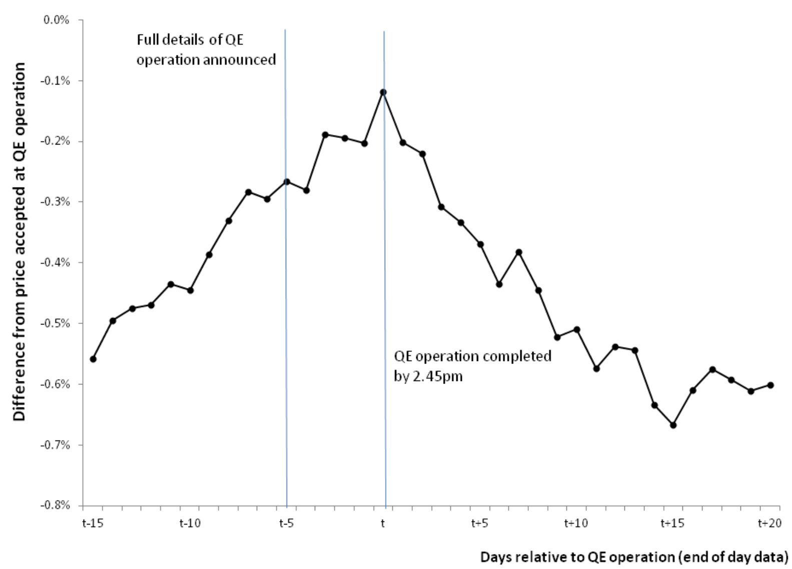

Figure 10. Average Price Response around QE Operations