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Abstract

The financial crisis and subsequent economic recession led to a rapid increase in the issuance of public debt. But large-scale purchases of bonds by the Federal Reserve, and other major central banks, have significantly reduced the scale and maturity of public debt that would otherwise have been held by the private sector. We present new evidence that tilting the maturity structure of private sector holdings significantly influences term premia, even outside crisis times. Our framework helps explain both the bond yield conundrum and the effectiveness of quantitative easing. We suggest that these findings raise two important policy questions. One is: should a central bank, contrary to recent orthodoxy, use its balance sheet as an additional complementary instrument of monetary policy to influence, as part of the monetary transmission mechanism, the long-term interest rate? The second is: how should central banks and governments ensure that debt management properly takes account of the implications for both monetary and financial stability?

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1. Introduction

Since 2008, the Federal Reserve and other major central banks have engaged in successive large-scale purchases of bonds. Initially these purchases served to restore confidence in markets gripped by panic. As market liquidity and functioning have improved, however, these policies evolved into a tool for further reducing long-term interest rates and stimulating economic activity. Today the Federal Reserve and other central banks continue to buy, or in some cases at least hold, bonds in the hope of stimulating aggregate demand.

Such purchases mark a break with the monetary policy orthodoxy that prevailed in the two decades or so before the crisis. Open market operations in bond markets were then seen as largely ineffective – and in any case not needed to steer the yield curve. Yet central bank bond purchases clearly had a significant impact on the yields during the crisis, as the net supply that the private sector had to absorb was attenuated. Much more striking, however, is the finding of several recent studies that operations that change the maturity structure of government bonds held by market participants have influenced term premia, even in the so-called "normal times" that preceded the crisis. These findings first raise the question whether central banks, contrary to the earlier orthodoxy, should use their bond holdings as an additional complementary instrument of monetary policy, aimed at influencing the long-term rate.[1]

Any decisions that significantly impact on long-term rates would inevitably have implications for both monetary and financial stability. And given that the maturity structure of debt before the crisis was mainly determined by the financing decisions of government, we may go on to challenge the notion that government debt management can be thought of as a policy problem quite separate to that of the central bank's choice of the short-term interest rate. To the extent that these effects are not internalised by debt managers, the effectiveness of monetary and financial policy in achieving their objectives could be compromised.

A resolution of these co-ordination questions may become essential as the economy improves and central banks prepare to staunch their bond purchases. Two further issues may in fact constrain monetary policy on the exit. The first is the build-up of concentrated interest rate exposures in the financial system, which

[1] Whatever economic theory may suggest, however, movements in long-term interest rates always figured prominently in the actual deliberations of central banks. Sometimes central banks have an explicit mandate for the long term rate. The Federal Reserve, for instance, has a triple mandate: "…. to promote effectively the goals of maximum employment, stable prices and moderate long-term interest rates" (Federal Reserve Act of 1977). Not just a dual mandate!

would call for a gradual increase, or normalisation, of long-term rates, but which has also the potential of dragging the central bank into a "low interest rate trap". The second is the possibility that faced with a large debt overhang, or even ongoing fiscal deficits, the government may alter the maturity of its debt issuance in order to frustrate attempts by the central bank to raise long-term rates.[2]

In this paper we review the importance of central bank operations in government bond markets – or equivalently debt management – both in theory and practice (Section 2). We present some evidence for the United States that changes in the maturity of the US government debt could have a sizeable effect on long-term interest rates over and above the path of expected future short-term rates (Section 3).[3] We discuss the risks and challenges that the Federal Reserve may encounter as it prepares to reduce its accommodation and in the future exit (Section 4). And we conclude by summarising the main questions that policymakers and researchers will have to address in the years ahead to ensure a smooth coordination between different government agencies (Section 5).

2. How central banks affect the long-term interest rate

The long-term interest rate on government bonds is a key variable in the transmission of monetary policy to aggregate spending because it influences lending contacts and because it may have net wealth effects through asymmetric changes in the valuation of long-term assets and the present discounted value of future liabilities. Firms borrow through a mix of short-term and long-term loans and bonds. In several countries, such as the United States, household mortgages have their rates fixed for several years. By influencing the current market value of future benefits and costs, the long-term interest rate exerts a pervasive impact on financial planning of all kinds. For instance, individuals take into account current and expected future interest rates to form their saving and pension plans. In addition to these traditional demand effects, there has been an increasing recognition in recent years that the level and the shape of the yield curve may also have an important influence on the degree of maturity transformation performed by the financial sector and hence on the amount of credit and liquidity that is made available to the real sector.

Yet before the recent crisis, most central banks in advanced economies settled on a recent orthodoxy by relying almost exclusively on an overnight interest rate as

[2] There is a danger of being trapped in a regime of fiscal dominance with active fiscal policy and passive monetary policy: see BIS (2012).

[3] We do not explore yields in non-US bond markets. Such markets, inevitably strongly influenced by US yields, are probably less susceptible to purely domestic factors than are US markets.

their only policy instrument. They would let the market determine longer-term interest rates, which were seen as depending on the predictability of its future policy rates. They did not seek to directly affect long-term rates through their own transactions.[4]

Long-term rates can be seen as the sum of two components. The first is the average forecasts of future short-term rates (that is, the expected return from rolling over investments in a sequence of short-run bonds). The second is the term premium.[5] Normally this is positive because the average investor demands compensation for taking the risk that the bond price falls (eg if the short-term interest rate or inflation rises more than expected).[6] Panel A of Graph 6 below shows a clear downward trend in the term premium, which started before the crisis.

In the absence of explicit guidance (e.g. a central bank's interest rate forecasts or time-contingent or state-contingent forward guidance), market participants would rely on public and their private knowledge of the central bank's objectives, economic models and their forecasts, reputation and past behaviour in response to economic news to predict how the central bank would set its short rates in the future. By actually making those decisions, and explaining effectively why, the central bank would thus shape those market expectations. According to this thinking, success in keeping inflation low and stable (and reducing interest rate volatility) would contribute to keeping term premia low and stable as well.[7]

This view of the monetary transmission mechanism – based on the expectations theory of interest rates and the ineffectiveness of open market operations – was at the core of the standard New Keynesian model (e.g. Eggertsson and Woodford, 2003; Curdia and Woodford, 2011). This model provided the intellectual underpinnings of central banking in the two decades preceding the crisis in which money was simply a veil over optimal expenditure plans (for a critique see Chadha, Corrado and Holly, 2013).

The open question is whether the effects of central bank purchases on yields are entirely due to the financial stresses, the illiquidity and special conditions

[4] Open market operations (usually in government bills) were only used to support the implementation of the overnight interest rate in the interbank market.

[5] The term premium may be a collection of various time-varying premia, including liquidity, credit and inflation risk, as well as time preference.

[6] The expectations theory of the interest rate assumes that bonds of different maturities should be perfectly substitutable. Arbitrage would ensure that the interest rate on a n-period bond, equal the (geometric) average of the interest rates on n consecutive one-period bonds. However, if the investor plans to sell the bond before redemption, holding a long-term bond is risky because the short-term interest rate could rise. For that reason such an investor would demand compensation, or a term premium. Other investors – normally a minority – may want to "lock in" current interest rates, and so be willing to pay a premium.

[7] There is evidence that, when inflation expectations are well-anchored, the yield curve tends to be flatter (see e.g. Gurkaynak and Wright, 2010).

prevailing in bond markets over the financial crisis, or whether they reflect channels that had already been at work in 'normal times'. In the latter case, open market operations in bond markets – or equivalently government debt management – might prove useful not only in fighting off future financial panic but also as a complementary instrument of monetary policy.[8] If so, the New Keynesian model would have to be radically re-thought.

Central bank assets: theory and practice

Government debt management was a key part of monetary theory and practice from at least 1930 right up to the 1980s. The monetary authorities – central bank along with the government – had the capacity through their transactions to alter the portfolios of assets held by the private sector. Key interest rates would change to induce the private sector to hold this new portfolio.

In both the *Treatise on Money* and the *General Theory*, Keynes (1930; 1936) argued that the authorities should be ready to alter the maturity of their government debt to further their macroeconomic objectives: "Central banks are always too nervous about buying long-term paper". Yet his advice at that time went unheeded. The British government lengthened the maturity of gilts in the 1930s, thus weakening the scale of the monetary policy expansion intended by the abandonment of the Gold Standard (which allowed short-term rates to fall) and by foreign exchange intervention designed to depreciate sterling (see Allen 2012). But Keynes won the argument in 1945 at the National Debt Enquiry and keeping long-term rates down became a key aim of UK monetary policy in the immediate post-war period.

The *Radcliffe Report* in 1959 on the working of the UK's monetary system also gave prominence to debt management.[9] The Report noted several instances when changes in Bank rate were insufficient to effectively implement a change in the stance of monetary policy. In an analysis that foreshadowed Greenspan's famous conundrum, the Report cited one episode in which long-term rates did not follow short rates upwards. In the early 1950s, rising short rates did not, for several months, lead to higher long rates, thus partly frustrating the central bank's intention

[8] Central bank operations in government bond markets and government debt management policies both affect the maturity of government debt held by outside investors – that is, the private sector and foreign official investors. In this sense, they are equivalent. For a view of the impact of open market operations, see Breedon et al. (2012) p 704.

[9] The economists who gave evidence to the Committee (including Richard Kahn, Frank Paish and Harry Johnson) argued that monetary policy influenced aggregate demand via the long-term interest rate (Radcliffe Report, 1959). In an interesting prelude to much later work on money demand functions, Frank Paish established empirically an inverse relationship between the quantity of money and the long-term rate. For a summary of their views see Turner (2011a).

to tighten policy. After an extended lag, however, long-term rates did eventually rise, but by then a downturn had already begun.

One of the Report's key policy conclusions was that uncertainty about how and when higher Bank rate would affect the long-term rate meant that using open market operations to move the whole yield curve up could improve the chances of timing countercyclical monetary policy correctly. In modern parlance, their argument was that uncertainty about how changes in the policy rate would affect other interest rates (so-called instrument uncertainty) justified the consideration of an additional instrument. One such instrument could be purchases or sales of government bonds.[10]

Occasions could arise when sales or purchases of government debt would be preferable to relying only on the policy rate. For example, the size of the adjustment in the policy rate needed to have the desired impact quickly on the long-term rate could be too disruptive for borrowers with short-term credits. And it might need to be reversed if long-term rates were subsequently to overreact. Equally, market over-reaction to a policy rate change could destabilise the bond market, and call for central bank action to guide directly the long-term rate.

On this ground, the *Radcliffe Report* rejected HM Treasury's view that bond sales should not seek to influence the long-term interest rate. One of its conclusions was that: "the management of the National Debt … [is] an instrument of single potency … in influencing the structure of interest rates … the monetary authorities must exercise a positive policy about interest rates, long as well as short."

Around the same time, several economists began to provide more rigorous foundations for such portfolio rebalancing effects. Culbertson (1957) and Modigliani and Sutch (1966, 1967), among others, highlighted the existence of market segmentation and imperfect substitution between different maturities, proposing the preferred-habitat theory as a possible explanation. Tobin (1961; 1963) formulated formal models of these effects within the Keynesian tradition. In his *Program for Monetary Stability* and other writings, Milton Friedman (1960) also accepted the empirical relevance of portfolio rebalancing effects,[11] although he generally saw such operations more as an instrument for maintaining stable broad money aggregates in the face of a financial crisis than as a tool for activist monetary policy.

[10] Their reasoning echoes one of the principles of policymaking under uncertainty stated by Brainard (1967). In the face of instrument uncertainty, using all available instruments would deliver better outcomes than just one instrument even if there is one target. Brainard (1967) based this conclusion on a highly stylised model assuming standard preferences for risk. In practice, research is needed to clarify to what extent this principle would hold in a realistic model that incorporates portfolio balance effects.

[11] See e.g. the review by Nelson (2011).

McCauley and Ueda (2009) have shown that a similar "bills versus bonds" debate took place in the United States during the 1930s and Keynes urged the Federal Reserve to buy long-term Treasuries.[12] But purchases of government bonds by the central bank began in earnest only during World War II, and continued – as in the United Kingdom – in the post-war period. From 1942 to 1951, the Federal Reserve pegged bond prices so that the yield on very long-term bonds (25-year bonds) was capped at 2.5%, helping to sustain the recovery of aggregate demand as well as reducing public debt. Worries about mounting inflationary pressures led to the abandonment of the peg in 1951. The Federal Reserve then moved to a policy of "bills only" whereby it would set a target for the short-term interest rate and would only purchase bills to support it. The market was then let to determine the yields on longer-term bonds. Economists at the Federal Reserve reasoned that the short-term interest rate and the expectation channel gave them sufficient leeway to steer the long-term rate. Declining government debt and shortening debt maturities in the 25 years that followed the war put downward pressure on bond yields.

In 1961, the Federal Reserve agreed with the Kennedy's administration proposal of buying long-term bonds and selling short-term bonds. This operation, which became known as Operation Twist, was designed to lower the long-term rate even if the short-term rate was rising (partly to stimulate an inflow of capital and so support the dollar). When the operation ended in 1963, long-term rates declined somewhat but, as empirical analyses failed to find a clear link with the change in relative bond supplies (Modigliani and Sutch, 1966), many economists remained doubtful about its effectiveness. Foreshadowing some of our results and the problems of estimating the impact on yields of debt management operations, other economists instead argued that any effects from Federal Reserve purchases had been offset by the Treasury issuing more long-term bonds, which caused the outstanding amount of bonds in the market to rise (e.g. Tobin, 1974; Solow and Tobin, 1987).

Since that time (but before the recent crisis), the Federal Reserve refrained from trading in long-term bonds. One argument put forward was that bond purchases were a much less reliable instrument for influencing long-term rates than the short-term interest rate (Meltzer, 2009).[13] Nevertheless, certain episodes, which saw

[12] See Tily (2010), pp 69–76.

[13] Meltzer (2009, pp 1001–2) quotes a May 1975 memo of the Board staff arguing that Federal Reserve purchases of bonds would be quite ineffective. He explains that the issue arose under the usual pressure from Congress to assist the housing industry by buying long-term securities in order to lower long-term rates. The memo questioned the ability of the Federal Reserve to influence long-term rates:

"the expectations theory now generally accepted as the best explanation of the term structure of interest rates and empirical tests of changes in the maturity distribution of securities held by the

the fiscal agent of the government rather than the central bank acting, did provide additional evidence about the power of bond purchases. Following several years of large fiscal surpluses in the second half of the 1990s, for example, the United States Treasury conducted a number of buyback operations in the early 2000s. Although without reaching firm conclusions, Bernanke, Reinhart and Sack (2004) used a term-structure model to show that these operations may have reduced the yields of 20-year residual maturity bonds by almost 100 basis points.

Bond market operations have also played a role in the attempt to curb fast money growth. For example, between 1978 and 1984, the UK government issued long-term bonds in excess of financing requirements (this so-called "overfunding" operated to the tune of about 5% of GDP, or about £75 billion at present day GDP). The idea was that sales of bonds to non-banks would curtail broad money growth and curb inflation much more effectively than just by increasing the Bank rate (Turner, 2011b).

What about Japan's striking experiences of bond purchases, which began in the early 2000s? Government bond purchases by the Bank of Japan do not at first sight appear to have lowered the 10-year JGB yield (Ueda, 2013). However, the Bank of Japan had, before the arrival of a new Governor in March 2013, avoided buying government bonds with a maturity greater than three years – mainly because of their aim of "not undermining the government's budget deficits". In addition, there was an offsetting change in government debt management policy: the average maturity of newly-issued bonds was lengthened from 5 to 8 years in the period from 1999 to 2012 (Iwata, 2013).

Modern theory of the yield curve

The ambiguity raised by the empirical evidence in favour of portfolio rebalancing effects led many economists to place more weight on new theoretical reasoning. The prevailing macroeconomic orthodoxy that emphasises complete markets leaves little room for effective open market operations. The apparent deepening of financial liberalisation and innovation led to greater faith in the efficiency of financial markets and the ability of sophisticated investors to arbitrage away any price differences between assets with similar characteristics.[14] This new thinking,

public suggest that even very large desk purchases of Treasury coupon issues exert only limited, short-lived effects on levels of long-term rates and their relation to short-term rates."

[14] The Modigliani-Miller theorem and Ricardian equivalence stressed how the distribution of assets between the public and the private sector should not make a difference to asset prices. Fully informed forward-looking agents would anticipate that any loss or gains in the assets held by the government would eventually be reflected in their future tax liabilities and would adjust their behaviour in such a way to neutralise any change in the asset composition on asset prices (see e.g. Wallace (1981), Chamley and Polemarchakis (1984), and Sargent and Smith (1987), among others). Any friction such as the existence of liquidity constraints which could break such neutrality were

encapsulated in the standard New Keynesian model, led even practical central banks to neglect money and liquidity.

The shortcomings of this model have been laid bare by the crisis. The search for richer theoretical models is on. One notable development is the model of interest rate risk by Vayanos and Vila (2009), which follows the tradition of the preferred-habit theory originally developed by Culbertson (1957) and Modigliani and Sutch (1966, 1967). Vayanos and Vila (2009) have constructed a model around two basic assumptions. The first is the existence of heterogeneous preferences about the maturities that some agents want to hold. For example, pension funds may be extremely averse to interest rate risk, or may face regulatory restrictions that require them to match the maturity of their assets to that of their liabilities. The second assumption is the imperfect ability of arbitrageurs to undertake maturity transformation across the yield curve.[15]

In this model, the initial effect of an expansion in the supply of long-term bonds, given unchanged demand, is that bond prices fall. Arbitrageurs would then buy the cheaper long-term bonds (reversing part of the initial decline) in exchange for the short-term bonds (whose price would rise). But the initial gap in prices would not be eliminated completely because arbitrageurs would demand a larger risk premium to cover the interest rate risk from holding a larger stock of long-term bonds. The quantum of this risk can vary over time, being greater the larger is the uncertainty about future path of short-term interest rates. Macroeconomic or financial crises can clearly accentuate such a risk; and risk appetite is also time-variant. Moreover, capital and liquidity constraints, which often tighten in a crisis, limit arbitrageurs' ability to bear this risk. Consistent with this theory, Greenwood and Vayanos (2010) find that a rise in the relative supply of government bonds is positively associated with yields and excess returns over short-term bonds and that the effects are stronger at longer maturities. The yield curve thus shifts up as its slope increases.[16]

Debt issuance policies and central bank open market operations aimed at shortening maturities have an ambiguous effect on financial stability. One line of reasoning, related to the supply of safe and liquid assets, suggests that issuing shorter maturities may help financial stability. Stein (2012) has pointed out that

considered of second-order importance (or too complicated to incorporate in existing theoretical models). See e.g. Zampolli (2012) for an overview.

[15] For a version of this idea in a business cycle model, see Harrison (2011). We explore some of the implications of central bank bond purchases and sales in a related model in the Appendix.

[16] Evidence that the supply of public debt influences interest rates had also been provided before the crisis by e.g. Bernanke, Reinhart and Sack (2004) and Kuttner (2006). The effects of central bank non-standard policies are estimated in Gagnon, Rasche, Remache and Sack (2010), Doh (2010), D'Amico and King (forthcoming) and D'Amico, English, Lopez-Salido and Nelson (2012). Swanson (2011) revisits the effects of "Operation Twist" in the 1960s.

when there is a shortage of short-term safe assets, private banks tend to fill the gap. Greater or more imprudent maturity exposures may mean they create more liquidity than they are able to sustain in a crisis. Once sentiment turns, the economy is then exposed to a sudden reversal in the supply of liquid assets. And fire sales of assets hurt banks. The severity of the recent financial crisis owed much to excessive maturity transformation by financial institutions (often via opaque financial products) that were ill-equipped for such a function. If financial regulation and supervision are not enough alone to control the supply of privately-created liquidity, it would be better for the authorities to issue more short-term debt. Because it can print money and raise taxes, the public sector – providing it is believed that its present value budget constraint will be respected – has an advantage over the private sector in bearing refinancing risk (Greenwood, Hanson and Stein, 2010).[17]

A contrary line of reasoning is that maturity-shortening policies operated by the monetary authorities could drive the long-term interest rate too low. The long-term rate (and the associated term premium) has a pervasive influence on financial stability. In the absence of sovereign default risk, the long-term interest rate on government bonds defines the credit risk-free maturity transformation over time. It thus provides the basic interest rate for discounting future income and payments and is central to the pricing of all long-term assets: accordingly, if the long-term rate is "too low", the prices of long-term assets can be "too high". In particular, it influences the market value of assets that potential borrowers can pledge as collateral for getting new loans. Such collateral effects could in turn encourage banks to expand lending beyond what is socially optimal. Given these potentially opposing effects, the implications of debt management policies for financial stability are still very open to debate. It would also seem clear that both effects have the propensity to amplify, or at least complicate rather than clarify, the impact of a particular policy stance.

3. Empirical evidence

This section summarises our empirical evidence that lengthening the maturity of US Treasuries held by outside investors raises the long-term interest rate relative to the expected path of future short-term rates. Because this evidence is based on the

[17] See also Krishnamurthy and Vissing-Jorgensen (2012) who find that public debt is inversely related to measures of private money. Krishnamurthy and Vissing-Jorgensen (2013) present preliminary evidence that the net supply of bills (i.e. the difference between the stock of government bills and those created by the private sector) is a better predictor of financial crisis than other measures such as the credit-to-GDP ratio. For a general discussion of liquidity and monetary policy, see Gale (2011).

pre-crisis period (unlike post-crisis event studies of QE), the effects we have identified cannot be ascribed only to the unusual disruption of market functioning during the crisis. The analysis by Laubach (2009) of the determinants of the long-term interest rate is extended by the inclusion of a variable for the average maturity of public debt, which proxies the average duration risk taken on by investors. Chadha, Turner and Zampolli (2013) provides further details of the econometric analysis.

A challenge in analysing the effects of debt (or deficit) on long-term interest rates is to separate long-run effects from the short-run or cyclical ones. Since slower economic growth is likely to both lower long-term interest rates and raise public debt, any estimates of the debt effects could be biased downward. To overcome this problem, Laubach (2009) uses expectations of future long-term interest rates as well as expectations of future debt: such variables should be less influenced by the business cycle and by current expectations of future interest rates than the contemporary 10-year yield. He employs the 5-year forward 10-year government Treasury bond yield as dependent variable.[18] As to the debt projection, he uses the 5-year-ahead projections of the Federal debt-to-GDP ratio (or 5-year-ahead budget deficit), which has generally been produced twice a year by the Congressional Budget Office (CBO) since 1976.

In addition, Laubach (2009) controls for trend growth (which is found to be statistically insignificant) and for the stock market dividend yield. The latter is meant to proxy investors' risk aversion and is therefore expected to be negatively related to the long-term interest rate: as investors become more risk averse they shift their portfolio from equities to government bonds.

The specification employed in Chadha, Turner and Zampolli (2013) is:

(1) $$f = \alpha\pi + \beta g + \delta\left(dy\right) + \gamma m + \lambda\left(Tbvol\right) + \mu\left(Divid\right) + \varepsilon$$

where:

f = 5-year forward yield on 10-year Treasuries

π = Long-horizon inflation expectations by market participants and professional forecasters (published by the Federal Reserve Bank of Philadelphia)

[18] The 5-year forward 10-year government bond yield is constructed from the implied (one-year) forward interest rate curve, by averaging the maturities between 5 and 15 years. Roughly speaking, it should correspond to the expected average short-term interest rate between years 5 and 15 plus the relevant 10-year term premium. Since the former expectation is several years into the future, it should be less influenced by current and near term monetary policy. Indeed, Chadha et al. (2013) find that business cycle variables (including the short-term interest rate) have no statistically significant effect.

dy = 5-year ahead projections for Federal debt as a percentage of GDP, generally released twice a year by the US Congressional Budget Office (CBO), which are first available in 1976

m = Average maturity of Federal debt held outside the Federal Reserve, in months

g = 5-year ahead projection of GDP growth by the CBO (or a proxy for trend growth)

Tbvol = Volatility of short-term interest rates, viz the 12-month rolling standard deviation of the 3-month Treasury bill rate

Divid = Stock market dividend yield as a measure of risk aversion.

The sample is made up of semi-annual observations from 1976 to the first half of 2008 and the regression is estimated by OLS with Newey-West standard errors. The main difference with Laubach's (2009) analysis is the inclusion of a variable for the average maturity of government debt (that is, *m*). There are two additional differences. The first is that we control for the volatility of the short-term interest rate (*Tbvol*). The second is that we conduct a preliminary structural break analysis to check that the parameters are stable over the sample. Our finding is that there is break around 1986 and that the variables *g*, *Tbvol* and *Divid* are statistically significant only before that date.

The regression results are summarised in Table 1. The average maturity of government debt is highly significant and suggests a sizable effect: shortening the average maturity of Federal debt held outside the Federal Reserve by one month lowers the long-term yield by 12-13 basis points. This effect is robust to dropping trend growth (column 2), the dividend yield (column 3) and the volatility of short-term interest rates (column 4). Re-estimating the equation using 1986 as the start period (the date of the break) does not alter these conclusions whether we control or not for trend growth and the dividend yield (Columns 5 and 6).

The estimates of the other relevant coefficients are also significant, and of reasonable magnitude:[19]

- A one percentage rise in long-horizon inflation expectations adds about one percentage point to the 10-year yield.

[19] One exception is trend growth, which is proxied by the CBO's 5-year projection of real GDP growth. Its estimated coefficient is found to be statistically significant and negative for the period before 1986 (and statistically insignificant thereafter) (column 1). Based on theory we would have expected a positive coefficient. Further investigation revealed that this result is driven by the initial observations in the sample. Re-estimating the model from 1980 onward yields a positive but statistically insignificant coefficient. We believe that this is due to an artefact of the data – the specific proxy used – rather than the empirical specification. Laubach (2009) also finds trend growth to be negative but statistically insignificant. We therefore drop it from our baseline regression.

- A one percentage point rise in the debt-to-GDP ratio five year ahead is associated with about 2 basis points increase in the forward rate, a finding that is very close to what found by Laubach (2009) in his regressions.
- Greater volatility in the short-term rate drives up the long-term rate. Note that the effect of debt becomes insignificant when the variable *Tbvol* is dropped. Dividing the sample into two subgroups showed that allowing for volatility in the short-term rate was necessary to identify the effects of the debt-to-GDP ratio in the earlier period, when short-term rates were more volatile.
- Greater risk aversion (as proxied by the dividend yield) drives down long-term interest rates.

These findings are also robust to the inclusion of business cycle variables such as the 3-month Treasury bill rate and a real-time estimate of the output gap; the size of the Federal Reserve's holdings of Treasuries; and purchases of Treasuries by the foreign official sector. (Full details can be found in Chadha et al, 2013).

Moreover, re-running the same regressions with an estimate of the 10-year term premium as dependent variable (and using a sample that starts from 1990) leads to similar conclusions (Table 2).[20] Across the different specifications, the effect of changes in average maturity was between 10 and 13 basis points. The average maturity of debt was again significant. The debt-to-GDP ratio, however, was insignificant; but the CBO's 5-year-ahead projection of the budget deficit was significant.

In our view these results are likely to be subject to some endogeneity bias as they implicitly assume that decisions on the maturity of debt issued are independent of prevailing interest rates. If they are not independent, the coefficient on the average maturity term could be biased (see Chadha et al, 2013, for a fuller discussion, in particular Annex 3 pp. 33-4). But we believe that any bias should be relatively small because several changes in maturity over this sample period were the result of legislation – and so can be treated as exogenous.

The estimates of the maturity effects could potentially shed some light on both Greenspan's conundrum and the effectiveness of Quantitative Easing.

Greenspan's conundrum

In February 2005, Fed Chairman Greenspan complained that the long-term interest rate had continued to fall even though the Federal funds rate had been raised by 150 basis points to 2.5 per cent. In his view there was no obvious explanation, and he famously called this a "conundrum". And subsequent increases in the Federal

[20] Estimates of the 10-year term premium are described in Hördahl and Tristani (2010).

funds rate, up to 5.25 per cent in July 2006, did not push up the 10-year long-term rate as much as it had in previous tightening episodes. Increases in the policy rate were instead offset by a sizeable decline in the term premium.

One important reason for the decline in the term premium that took place during the early 2000s was the shortening of the maturity of US public debt in the market. Average maturity peaked at 73 months in September 2001; it then steadily declined to reach a trough of 56 months in March 2005, soon after Greenspan's remarks; and remained very close to an average of almost 58 months until July 2007. Based on the estimates presented in Tables 1 and 2, a shortening of the maturity of over one year would have compressed the term premium by more than 150 basis points. Moreover, the relative stability of average maturity since mid-2005 could explain why long-term rates moved up by less than had been initially expected.

Effects of quantitative easing

The regression results can be used to assess the impact of the large-scale asset purchases or Quantitative Easing (QE). The first round of QE was announced in November 2008.[21] Between then and the end of 2012, marketable Treasury debt (including Federal Reserve holdings) rose 28.5 percentage points of GDP, whereas debt held outside the Federal Reserve rose by 21.5 percentage points of GDP (Graph 1). Hence, the Federal Reserve has absorbed about 7 percentage points of the extra debt.

Marketable debt outstanding (including Federal Reserve holdings) had an average maturity of 49 months in November 2008, compared to 46 months of debt held outside the Federal Reserve (Graph 2). In the following years it rose, reaching 65 months at the end of 2012, whereas the maturity of non-Fed-held debt rose to 55 months. Taking November 2008 as a cut-off point, the gap between the two average maturities thus rose from 3 to 10 months. If we assume that without central

[21] The Federal Reserve engaged in four rounds of these purchases. In the first round (or QE1), the Federal Reserve bought some $1.75 trillion of assets over the period November 2008 – March 2010, of which $300 billion (or 2.2% of 2009 GDP) were Treasury securities. In the second round (or QE2) it purchased about $600 billion of Treasuries between November 2010 and June 2011 (or 4% of 2010 GDP). In addition, as of August 2010, the central bank began to reinvest the principal from the expiring MBS into Treasury securities. By the end of June 2011, the amount reinvested reached $250 billion (or 2% of 2010 GDP). In the third round, announced on 21 September 2011 and extended in June 2012, the Federal Reserve purchased $667 billion (or 4.4 of 2011 GDP) of Treasuries with remaining maturities of six to 30 years and sold the same amount with remaining maturities of three months to three years. This Maturity Extension Program (MEP), reminiscent of the Operation Twist in the early 1960s, was designed to reduce the maturity of the debt held by the private sector without further increasing the size of the central bank's balance sheet. In the latest round, which was announced in September 2012, the Federal Reserve committed to open-ended purchases of agency MBS at the pace of $40 billion per month until labour market conditions improve markedly. In December 2012, this scheme was extended to include the purchase of $45 billion of Treasuries per month.

bank intervention this gap would have remained the same as it had been in November 2008, then central bank purchases contributed to changing the average maturity composition of debt held outside the central bank by about 7 months.

Graph 3 shows the joint impact on the five-year 10-year rate and the 10-year term premium of these two developments. Specifically, the absorption of 7 percentage points of debt translates into 12–15 basis points lower forward rate. A 7-month lower average maturity translates into approximately 81–100 basis points lower forward rate. Combining the two effects, Federal Reserve purchases since November 2008 may have therefore contributed to lowering the 5-year forward 10-year rate by approximately 90–115 basis points. The estimated impact on the 10-year term premium is a little lower.

These estimates are not too distant from those found in recent empirical studies that employ different data and methods. For example, D'Amico et al (2012) use weekly data on the average duration of debt held outside the Federal Reserve from 2002 to 2008, reaching the conclusion that the first two large-scale purchasing programmes (that is, without including the effects of the most recent Maturity Extension Program) have reduced long-term yields by about 80 basis points. Li and Wei (2012) estimate an affine term structure model modified to incorporate bond supply factors. The model is estimated with monthly data over the period 1994–2007 assuming that debt managers "do not time the market" (that is, that their decisions are independent of changes in the yield curve). The estimates suggest that the first three rounds of LSAPs might have lowered the term premium on the 10-year yield by at least 100 basis points.[22]

A lower term premium increases aggregate demand. While quantifying this impact would require a full model, some rough-and-ready indication of magnitudes is possible. A simple VAR model over the pre-crisis period 1986 Q2 to 2008 Q2 (featuring real GDP, a measure of inflation and the Federal funds rate) shows that a negative shock to the term premium has a significantly positive effect on real GDP. According to this calculation, the accumulation of such negative shocks from 2008 – which mainly took effect from 2011 – added about 3 percentage points to real GDP by the end of 2013. Other empirical studies suggest an impact of similar magnitude. For instance, simulations using the FRB-US macro-model suggest that a reduction of 100 basis points in the 10-year rate could have boosted GDP growth by between 2.4 and 3 percentage points over a number of years (Chung et al, 2012). Similarly,

[22] Running a regression on monthly data from 1985 to 2008, Gagnon et al (2011) estimate that the first round of long-term asset purchases by the Fed has reduced the 10-year yield by between 38 and 82 basis points.

Baumeister and Benati (2010) find an effect on US GDP of about 2.5 percentage points.[23]

Central bank asset purchases at the start of the crisis probably averted the risk of a more severe recession, but subsequent rounds of bond purchases, when the long-term interest rate was already very low, may have been less effective in stimulating growth. Some components of demand (e.g. residential investment and consumer durables) have been supported as the policies aided liquidity-constrained households. The effect on non-residential investment is less clear. This is because, once the term premium has become negative, a marginal further reduction in the long-term rate (expected future short rates given) will make it more profitable for firms to issue long-term debt in order to invest in short-term securities (or buy back shares). But it will not make it more profitable for a firm with no liquidity constraint to increase investment in plant and equipment (Stein, 2012a). The financial stability risks, on the other hand, may grow as the term premium becomes negative.

Are bond yields too low?

One possible way to assess whether long-term interest rates have become too low is to compare the current level of the forward long-term rate with the one predicted by the regression presented in Table 1. The 5-years forward 10-year yield fell from a range of 5 to 5½% in the pre-crisis years to 3 to 3½% from early 2012 to May 2013. Despite a severe recession and much talk of deflation risks, inflation expectations have fallen only slightly, if at all. Given the significant rise in both the expected future level of Federal government debt and the average maturity of debt held outside the Federal Reserve between 2008 and the present, the 5-year forward 10-year yield should have risen to about 5% (Graph 4). Another clue is offered by negative estimates of term premia. At first glance, negative premia are a puzzle because bond investors would be better off by rolling over holdings of short-term paper than investing in long-term bonds.[24]

Why then have long-term rates not risen? One reason is that investors were seeing their investment in long-term bonds as an insurance against the tail risk of a collapse in output and deflation. A more plausible explanation, however, is that several new, non-monetary factors might have increased the demand for government bonds. First, new prudential regulations, mark-to-market accounting rules, actuarial conventions, and other factors, are inducing banks, insurance

[23] See also IMF (2013) for a review and discussion of these effects. There is evidence that loan rates have fallen, but it is hard to tell how much of their fall fed into the rest of the economy.

[24] The sharp rise in bond yields from May 2013 to July 2013 (the time of writing) has corrected much of these anomalies. The 5-year forward 10-year yield rose to 4% and the term premium moved closer to zero.

companies, pension funds and other financial intermediaries to hold a higher proportion of their assets in government bonds. Second, the post-crisis fall in unsecured interbank lending and higher swap margin requirements have led to a higher demand for collateral in financial transactions in wholesale markets (a fuller analysis is provided in BIS, 2013).

Another reason may be that markets have come to be dominated by expectations of what a very large investor who is unresponsive to market prices (that is, the central bank) will do. By stating that purchases would continue steadily as long as the unemployment rate remains high, the Federal Reserve may have created the perception that investing in long-term bonds was almost a one-way bet. Focus on short-term returns, the expectation of capital gains from further declines in long rates and herd behaviour may have created downward inertia in long-term rates, fulfilling initial investors' expectations. In addition, the expectation of a steady stream of purchases may have created an impression of ample market liquidity, keeping yields low.[25] Federal Reserve statements in May 2013, however, served to counter such perceptions and warn markets not to rely on Federal Reserve purchases for ever (see below): this led to a large fall in bond prices worldwide. With bond markets so sensitive to news about an economic recovery, there is a significant possibility that bond prices may move in a volatile manner that may stifle the recovery. The exit from quantitative easing is now a prominent issue.

4. Exit from quantitative easing

The amount of government debt in the central bank portfolios is now very large. At the end of May 2013, the Federal Reserve held an amount of Treasuries equivalent to 11.8 per cent of GDP, which compares with an average of 5.5 per cent in the decade before the beginning of the crisis. This amount is set to rise further in 2013 and 2014 as the Federal Reserve continued to buy $85 billion every a month until activity has improved. Expectations at the time of writing are that this flow of purchases will begin to decline in September 2013 and gradually come to an end during 2014. After that, the Federal Reserve could decide to sell the bonds in its portfolio, let them mature so that its stock would gradually diminish, or could keep its stock constant by reinvesting the proceeds from expiring debt.[26] As the Federal

[25] The flow of purchases, rather than the overall stock, would probably be more relevant for market liquidity.

[26] In his testimony to the Congress (17 July 2013) Bernanke indicated that "even after purchases end, the Federal Reserve will be holding its stock of Treasury and agency securities off the market and reinvesting the proceeds from maturing securities, which will continue to put downward pressure on longer-term interest rates, support mortgage markets, and help to make broader financial conditions more accommodative."

Reserve stops adding to its holdings, any increase in the total stock of public debt (determined by fiscal policy) will have to be absorbed by the market. Graph 5 illustrates this point by showing how much of the projected federal debt over the next decade will be held by the Federal Reserve and how much by the market. Based on the latest CBO projection (May 2013), debt is expected to peak at 76% of GDP in 2014 and then decline to around 71% in 2018. It will then rise again towards 74% in 2023.

The breakdown is calculated under two assumptions. The first assumption is that the Federal Reserve lets its portfolio of Treasuries expire without replacing them as of end of May 2013. This is unrealistic but gives a useful benchmark to understand the consequences of current policy decisions. In this case, the debt held outside the Federal Reserve would rise from 62% of GDP to 72% by end-2023 with the increase concentrated in the latter half of the decade (Graph 5, left panel). The second (more realistic) assumption is that the Federal Reserve begins reducing its purchases in September, cutting the amount purchased by $5 billion a month until it hits zero in May 2014; and from then onward it keeps the stock constant in nominal terms. In this case debt held by the market would increase by only some 3 percentage points to 65% of GDP by end-2023 (Graph 5, right panel). Furthermore, if the Treasury continues to issue a greater share of long-term debt, the increasing stock held by the market will also have an ever longer average maturity over time, even if the Fed halts its purchases and keep its stock constant.

Policy choices in an exit strategy

There is great uncertainty about the timing and the speed with which central banks will reduce their holding of bonds (either by letting them run off or by sales). Because the Bank of England and the Federal Reserve currently hold more than 30% of their respective marketable government debt with maturities of 5 years or more, any decisions about sales could well have a significant impact on market prices. And news of any central bank sales could send markets a signal that is more powerful than the actual sales. Financial markets know how large the stock of central bank bond holding is and they also know central banks are uncomfortable with such holdings. Market participants also know that central banks have great strategic power as non-commercial players.[27] The hyper-sensitivity of markets is illustrated by the turbulence in global bond markets in late May and June 2013 (Panel B, Graph 6), triggered by Bernanke's statement that Federal Reserve purchases would, at some

[27] As El-Erian (2012) puts it, "in game theoretic terms, central banks are *non-commercial players* … [they have] a printing press … and the *structural patience* that far exceeds the ability of any other participant to remain in the trade."

future date, be reduced. The US 10-year yield rose about one percentage point and volatility increased.

Central banks have given a few general indications of how they would reduce their portfolios of bonds. The Bank of England has stated that it would begin to sell bonds only after it has begun to raise the policy rate. It would "work closely with the DMO" to "avoid generating unnecessary volatility in the gilt market" (see Fisher, 2010). The FOMC at their meeting in June 2011 laid down some principles for the exit strategy. One was that purchases of bonds would stop before the policy rate was increased. Another was that sales of agency securities (no mention was made of Treasury securities – see below) would come only after the first increase in the Federal funds rate.

Balance sheet and interest rate policies are, to some degree, substitutes. Indeed, the FOMC minutes in April 2011 revealed that participants noted that "for any given degree of policy tightening, more-gradual sales that commenced later in the normalisation process would allow for an earlier increase of the federal funds rate target from its effective lower bound than would be the case if asset sales commenced earlier and at a more rapid pace".

How could the central bank proceed in normalising monetary policy after the first rise in the policy rate has been decided?[28] At one extreme, the central bank could seek to retain complete discretion. Even so, it would still have to clarify how it would coordinate with the fiscal authority. As the former Governor of the Bank of England has noted (King, 2012), however, the central bank must keep the ability to sell the government bonds on its balance sheet if needed to maintain control of inflation, monetary conditions and the supply of credit. Because no central bank would want to be seen as making the financing conditions of long-term government debt more difficult, it may be desirable for the central bank to swap with the Treasury its long-term bonds for Treasury bills or for floating rate Treasury bonds. Such an operation would have no effect on the debt in the market, but would make government financing costs more dependent on short-term interest rates. This may increase government pressure on the central bank.

At the other extreme, the central bank could commit to some long-lasting rule specifying what it will do and how. A rule could simplify coordination with the Treasury as well as help stabilise market expectations. But it could quickly lose credibility if it is not reviewed periodically or if it does not allow enough flexibility. Balancing the need to stabilise market expectations with the need to adapt to an

[28] Turner (2013) outlines a schematic decision-tree for an exit strategy. He describes possible "rules" that central banks could follow in exiting their balance sheet policies as well as the issues that might arise when central banks act in a completely discretionary way.

uncertain and changing reality make it more likely that any rule (that is, announcement or commitment) by central banks will be limited in time and scope.

In making a commitment, there are several general options that the central bank could consider. To cite the most obvious, the central bank could commit not to cease purchasing new debt as current bond holdings mature. Alternatively, it could announce a fixed amount of sales to be executed over a given time frame.[29] Any announced plan of sales could also come with specific conditions attached. For example, sales could be made contingent on the borrowing needs of the government (e.g. by preventing sales when deficits are above a certain level): this would, however, have to be communicated in ways that do raise a suspicion of fiscal dominance. Sales could also be halted if market volatility were higher or yields already rising strongly. An explicit interest rate ceiling could be applied. There are, however, obvious traps for any central bank that attempts to limit prices of government debt.

Long-term interest rates, even after the recent sharp jump, are still at the time of writing (July 2013) very low. How fast long-term rates should be allowed to rise in an exit will depend on at least two important considerations. The first is the impact on the balance sheets of financial firms. The second is the direct impact on government financing costs.

Interest rate exposures

A prolonged period of very low long-term interest rates and large budget deficits has increased interest exposures or made them more concentrated in some sectors of the financial system. The total potential impact of a fall in government bond prices on the private sector and on non-US official holders must have increased substantially over the past five years because the stock of government bonds held outside the central bank has risen so much. Longer-dated US Treasuries held outside the central bank increased by almost $5 trillion from mid-2007 to end-March 2013 (Table 3). At the same time, the weighted average of yields fell from 5% to 0.9%. Real yields are negative, well below the long-run historical average of about 3%. Investors thus face a significant risk of capital losses once interest rates re-normalise.

In consequence, the central bank faces a dilemma. If it delays normalisation of monetary policy, low long-term rates should sustain the recovery. But such a policy could lead investors to misprice interest rate risk. If the financial system were to

[29] For example, the FOMC meeting in June 2011 stated that the timing and pace of sales would be communicated to the public in advance: once sales begin, the aim would be to eliminate "holdings of agency securities over a period of 3 to 5 years". No mention was made of Treasury securities.

become more fragile as a result, the central bank could then become even more reluctant to let long-term rates rise, making the system even more fragile. The later financial risks are checked, the greater the ultimate risk to monetary or financial stability.[30] One way of addressing this dilemma would be for the central bank to warn that it will halt purchases well ahead of time as part of a strategy of forward guidance. Bernanke's statement in May 2013 can be read in this light: in the market turbulence that followed, two-way risk was effectively re-established in bond markets. By reducing risk-seeking behaviour in markets, this action may allow policy rates to be held down for longer.

Assessing the financial stability risk of "low interest rates for long" is hard. Too little is known either about the distribution of interest rate exposures or about the likely operation of bond markets under stress, when leveraged investors are forced to sell. Nevertheless, a number of questions that policymakers would be asking themselves are:

1. *Where do these risks ultimately reside?* Significant interest rate exposure is probably with the banks, which have increased their holdings of government bonds since the onset of the crisis. Such exposures typically do not require much, if any, capital because local currency government bonds usually have a zero credit risk weight and because, under the current Basel framework, there is no minimum capital charge for interest rate risk faced by banks from their banking book holdings of government bonds.

   To compensate for their increased maturity exposures vis-à-vis the government, some banks may have shortened the maturity of their lending to the private sector. Such shifting of interest rate risk may increase the default risk of their borrowers. Likewise, other financial intermediaries (insurance companies, pension funds etc.) may also have shifted risks.

2. *How diversified are portfolios?* The riskiness of a bond depends not only on the variance of its own return but also on its covariance with other assets in the portfolio.

3. *How leveraged are interest rate exposures of investors?* A market dominated by leveraged investors will usually be volatile in a correction. Investors who finance bond holdings by short-term loans can be forced by their creditors to sell when the value of the bonds (pledged as collateral) falls. When market volatility rises, they can be subject to larger 'haircuts'. Forced sales by leveraged investors into a falling market have often been a major ingredient of bond market crises. The degree of volatility and the sharp price declines seen in the May/June 2013

[30] The literature has recognised this danger calling it a "low interest rate trap" (e.g. Giavazzi and Giovannini (2010).

episode of bond market turbulence suggest the presence of significant leverage.

4. *Do banks and other financial firms with leveraged positions have enough capital to withstand a sharp fall in bond prices?*

There have been many occasions when large exposures of banks to government bonds have constrained monetary policy. It was a huge problem for US banks in the immediate aftermath of World War II. As pointed out by Eichengreen and Garber (1990), operations had to be undertaken to reduce such exposures before the Federal Reserve could feel comfortable raising policy rates. In more recent years, increases in the Federal funds rate in 1994 hit hard a number of institutions with leveraged bond portfolios causing steep gyrations in government bond prices. The "measured pace" of tightening during 2004–05 was designed in part to avoid a similar destabilisation of bond markets. This made the financial industry complacent about the exposures of their balance sheets to interest rate and other risks. The financial system ramifications of changes in the long-term rate might have mattered more for the monetary policy decisions than many would care to admit.[31]

Government debt financing costs

The second constraint on policymakers is the need to finance current and future fiscal deficits. Any increase in interest rates will make government borrowing more expensive, and so worsen fiscal sustainability. And if governments persistently fail to find a solution to fiscal problems, agents may come to expect higher inflation. The logic, originally laid out by Sargent and Wallace (1981), underpins the Fiscal Theory of the Price Level (e.g. Sims, 1994).[32] This reasoning is that, with fiscal policy dominant, an increase in the price level (and hence a temporary rise in inflation) would be the only way to ensure that the intertemporal budget constraint of the government be satisfied. In this context, monetary policy could face some "unpleasant monetarist arithmetic": higher interest rates may succeed in limiting inflation today only at the cost of higher inflation in the future. In such a scenario

[31] A more detailed discussion of episodes of high public debt can be found in Turner (2013).

[32] Sargent and Wallace (1981) assume that public debt is fixed in real terms (ie perfectly indexed to inflation). Hence, if the private sector no longer wants to hold public debt, the only way the government can repay existing debt and financing deficits is by issuing money. In this case, seigniorage will raise the real resources needed to fund the budget. But as money demand falls, the required inflation needed to extract the same amount of real resources will be larger, which will cause a further reduction in money demand and so forth. In contrast, the fiscal theory of the price level assumes that debt is fixed in nominal terms so that inflation will rise (temporarily) to reduce the real value of outstanding debt to the present value of whatever resources the government will be able to collect in the future to serve its debt.

monetary policy is dominated by fiscal policy and will have to keep rates low to prevent worse outcomes (e.g. Leeper, 1991).

In the less extreme (but perhaps more likely) scenario that investors expect fiscal sustainability to be restored, monetary tightening may still be rendered less effective if government debt managers try to undo the effect of policy rate increases. For example, the Treasuries could react to the prospect of a steep rise in long-term yields by simply issuing more short-term paper, thereby lowering the average maturity of its debt.[33]

Reduction of bank reserves

The analysis of exit would not be complete without mentioning central bank liabilities. Asset sales by the central bank necessarily imply a fall in central bank liabilities. In most advanced economies, the main liabilities are cash or commercial bank reserves. Any reduction in bank reserves can occur directly (if the central bank sells assets to banks) or indirectly (from a contraction of broad money if the central bank sells assets to non-bank institutions, which run down their bank deposits).[34]

The size of bank reserves can have real economic effects. Even if they are not directly employed by banks to expand credit, they could still serve the purpose of reducing the tail risk of sudden illiquidity and bank runs. The amount of reserves held by the US banking sector has now reached a record of $2 trillion (or 12.5% of GDP).

The role of reserves in the exit strategy is a very much an open question. Most would normally regard central bank liabilities, at given interest rates, as reacting passively to decisions about assets (when the central bank sells bonds it reduces bank reserves). But this may not necessarily be the case. The authorities could, for instance, use policy instruments such as reserve requirements or bank liquidity rules to alter banks' demand for reserves (again, at a given interest rate), in which case central bank liabilities can hardly be regarded as passively reacting.[35] In any event,

[33] See also Cecchetti, Mohanty and Zampolli (2010) for a discussion of inflation risks arising from unsustainable fiscal positions.

[34] The analysis is different if the central bank sells to non-residents, which would tend to appreciate the currency.

[35] Siegel (2013) recently argued that the exit strategy could be better managed if the Federal Reserve were to impose a 15 per cent reserve ratio on banks (the Federal Reserve's "third policy tool" was the expression he used). In a similar vein, Goodhart (2013) argues that banks could be required to hold a higher proportion of their balance sheet in liquid assets ("financial repression" was the expression he used).

the task of managing the "veritable mountain" of excess reserves (Blinder, 2010) raises issues that go beyond the scope of this paper.[36]

8. Conclusion

At some point, central banks in the advanced countries will tighten monetary policy. In doing so, they now have two instruments – the policy rate and their holdings of bonds. (Arguably three instruments, if reserve requirements on banks or comparable liquidity rules were to be added). The relative reliance they will put on these instruments will be one influence on the yield curve.

But central bank policies will be only one influence – excessive bond market reactions may also be significant. Recall the bond market crisis that began in February 1994, when the Federal Reserve decided to raise the Federal funds rate by ¼ point, the first such steps for five years. This modest action, taken without any sign of imminent inflation, provoked a dramatic change in market sentiment and destabilised bond markets for a year. In current circumstances, after so many years of extreme monetary accommodation, it is hardly surprising that even the first hint of tightening in the United States – Bernanke's statements on 22 May about "tapering" bond purchases – provoked so much turbulence in global bond markets.

Reacting to a prolonged bond market crisis would be much more complex today given huge central bank holdings of government bonds. Should the authorities take a laissez-faire stance, and allow a steep drop in bond prices?

There are at least three dimensions of policy to consider, and on each dimension a plausible interventionist argument could be made:

1. *Monetary policy*. When markets are disturbed, and expectations not well-anchored, the substitutability between short-term and long-term paper declines. Therefore there could be very good monetary policy reasons for increased open market operations to hold down long-term rates (or to moderate their volatility) in periods of stress. The ECB has advanced this argument during the recent crisis. And the Federal Reserve is mandated by law to maintain "moderate long-term interest rates." The Chairman of the Federal Reserve Board recently noted that the Federal Reserve could use its balance sheet "under some circumstances, to

[36] The Federal Reserve began paying interest on such reserves in October 2008. The decision on the rate of interest to be applied to bank reserves is the responsibility of the Board of Governors, not the FOMC. As Blinder (2010) explains, this is significant because Chairman Bernanke has himself said that this interest rate – not the Federal funds rate – could be the more reliable guide to the stance of monetary policy in the early stages of exit.

dampen excessively sharp adjustments in longer-term interest rates" (Bernanke, 2013).[37]

2. *Financial stability*. Excessive market volatility can cloud the usual price discovery process. Banks, pension funds and insurance companies could all face heavy losses – at least in accounting terms – from mispricing. It could be argued that emergency bond purchases by the central bank would remove tail risks from markets and perhaps safeguard financial stability. The success of central banks in lowering long-term rates over the past couple of years will be remembered by those advancing this argument in the future.

3. *Government debt management*. The macroeconomic policy framework for such decisions is not clear. In a crisis, when investors become more reluctant to buy long-dated paper, it could make sense to issue short. On the other hand, it might be more prudent to keep issuing long as a precaution in case the crisis worsens. The recent euro area crisis illustrates the wisdom of such precaution.

There are, of course, obvious traps in all such arguments for intervention in what should be a market process. Any perception in markets that the central bank's commitment to price stability has been diluted could be self-defeating: note the evidence above that a rise in long-run inflation expectations has a one-to-one effect on the nominal long-term interest rate. And the effect would be larger still if inflation risk premia rise.

It is too early to know how these three dimensions of policy will interact in the years ahead. Any new policy framework would have to address many difficult questions. How to determine the range for any "optimal" level of the long-term rate, especially as it is likely to change over time? Could attempts to fix the yield of a target bond be vulnerable to Goodhart's Law?[38] How do attempts to lower long-term rates (narrowing or even reversing the term premium) affect the lending policies of banks? Do policies that lower long-term rates have macroeconomic effects that become weaker but financial side-effects that become stronger when the term premium is substantially negative as it is at present? What is the quantitative impact of changes in the policy instruments at the disposal of central banks on long-term rates? What logic should determine the maturity of debt issued by governments? How should measures aimed at long-term rates be coordinated with central bank decisions on the policy rate and with other economic policies?

Evidence that central banks purchasing government bonds (or government debt managers shortening the maturity of issuance) can lower the yield on

[37] He referred to the pace of sales of mortgage agency securities. As in the June 2011 FOMC minutes, no mention was made of government bonds.

[38] Goodhart's Law states that: "Any observed statistical regularity will tend to collapse once pressure is placed upon it for control purposes".

government bonds makes it difficult to evade such questions. The realisation, long dormant, that central banks and government debt managers both have the power to control long-term interest rates – within limits that are uncertain and dependent on market expectations – will doubtless spur further analysis. This paper has argued that, at least so long as central banks hold very large stocks of long-dated government bonds, government debt management and monetary policy will be closely linked. Certainly not tied at the waist, but perhaps bound to fail or succeed together.

Appendix – Modelling Monetary Policy and Debt Management

In this section we investigate the impact of bond purchases within the context of a calibrated general equilibrium model in which fiscal policy, debt accumulation and government, or central bank purchases of debt impact on the path of output. The model used here allows for wealth effects from public debt issuance because agents are finitely lived and may not bear the funding consequences of any given path of fiscal deficits. As well as a standard interest rate rule, we use a deficit rule that feeds back off from the output gap. This deficit rule, along with the sequence of interest rates, drives the debt level over time. We also draw upon a recently developed model (see Harrison, 2011), in which the representative agent lives in a standard optimizing economy with price stickiness, a New Keynesian Phillips curve and a forward-looking spending equation, albeit one in which there are interest rates of both short and long run maturity that tilt expenditure. The long-term rate differs from the expected stream of short term rates because of a preference for short term bonds, which drives up the liquidity premium on long term bonds. This implies that even at the zero lower bound the monetary policymaker has some ability to tilt expenditure by buying long term bonds and therefore reduce the liquidity premium.

We consider the impact on long term bond rates, and hence on demand, from a monetary authority's purchase of outstanding government bonds. A key parameter in this model is the impact on yield from a 1% purchase of the outstanding debt stock, which reduces net supply as well as shortens the maturity of debt. Given the empirical results presented in the paper we use a conservative estimate of 0.1, which implies that 1% purchase reduces long-term yields by 10 basis points. By embedding a fiscal response in this model, we can assess some of the trade-offs faced by the central bank and the fiscal authority.

Equation listing

We simply list the equations of this simple model and suggest the reader looks for the derivation in other papers.[39]

Euler equation (A.1)

$$c_t = \lambda\psi\frac{W}{C}E_t w_{t+1} + E_t c_{t+1} - (R_t^A - E_t\pi_{t+1}) + \varepsilon_{s,t}$$

[39] See Harrison (2011) for how to modify the utility function to incorporate a preference for short-run bonds and Chadha and Nolan (2007) for a description of the Blanchard-Yaari finite lives mechanism in discrete time.

Demand for money (A.2)

$$m_t = c_t - \frac{1}{1+\delta} R_t^A$$

Aggregate Wealth (A.3)

$$w_{t+1} = \left(\frac{m}{w}\right) m_t + \left(1 - \frac{m}{w}\right) b_t$$

New Keynesian Phillips curve (A.4)

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + \varepsilon_{\pi,t}$$

Resource constraint (A.5)

$$y_t = \left(\frac{c}{y}\right) c_t + \left(1 - \frac{c}{y}\right) d_t$$

Monetary Policy Rule (A.6)

$$R_t = \rho_m R_{t-1} + \varphi_\pi \pi_t + \varphi_y y_t + \varepsilon_{m,t}$$

Fiscal Policy rule (A.7)

$$d_t = \rho_f d_{t-1} - d\varphi_y y_t + \varepsilon_{f,t}$$

Government's budget constraint (A.8)

$$b_t + \frac{m}{b}\left(m_t - m_{t-1}\right) = (R_t^A - E_t \pi) + \frac{\left(1-\gamma\right)}{\beta} b_{t-1} + \left(\frac{\left(1-\gamma\right)}{\beta} - 1\right) d_t + \delta_1 q_t - \left(\frac{\delta_1}{\beta}\right) q_{t-1t+1}$$

Issuance of long-term bonds (A.9)

$$b_t^L = -q_t + V_t$$

Central Bank balance sheet (A.10)

$$q_t = \rho_q q_{t-1} + \varepsilon_{q,t}$$

Return on long bonds (A.11)

$$R_t^L = \beta E_t V_{t+1} - V_t$$

Average interest rate (A.12)

$$R_t^A = \left(\frac{1}{1+\delta_1}\right) R_t + \left(\frac{\delta_1}{1+\delta_1}\right) R_t^L$$

Term structure (A.13)

$$\nu\left(b_t^L - b_t\right) = E_t R_t^L - R_t$$

The consumption Euler equation (A.1) relates current consumption, c_t, to the present value of wealth, w_t, future consumption, $E_t c_{t+1}$ and negatively to the average real interest rate across long and short bonds, $R_t^A - E_t \pi_{t+1}$. E_t are expectations at time t. Demand for money, m_t, in Equation (A.2) increases in consumption and falls in the average interest rate. Financial wealth (A.3) in the next

period w_{t+1} is pre-determined and sums across money balances and the stock of public debt, b_t.

The New Keynesian Phillips curve (A.4) relates current inflation, π_t, to expected inflation, $E_t\pi_t$ and the output gap, y_t. Overall, the deviation in output from steady state is the sum of consumption and the fiscal deficit, d_t (the resource constraint, (A.5)). The short term interest, R_t, is set according to a standard rule (A.6), with arguments in the lag of the interest rate, R_{t-1}, inflation and output. The fiscal policy rule (A.7) relates the deficit to its lag and an argument in output. The key relationship is that of the government's budget constraint (A.8), which accumulates total public debt, b_t, according to the average real rate of interest of all debt, the current deficit and has matching increases in money according to the amount of quantitative easing being undertaken.

The government issues short and long term bonds. Long term bonds, b_t^L, pay a return, R_t^L whilst short term bonds pay a return equal to the policy rate, R_t. V_t is the value of a consol (infinitely lived with no redemption date) and q_t is the level of assets purchased by the central bank to facilitate quantitative easing. According to (A.9), the value of consols is determined by long term bond issuance, b_t^L, plus any q_t, which takes bonds out of the system and replaces them with money. Equation (A.10) gives the central bank's balance sheet in terms of bond purchases and lagged bond purchases. The return on long term bonds, R_t^L, is the expected change in the value of the bonds, (equation A.11). The economy-wide average interest rate is a combination of the long bond rate and the policy rate as given in (A.12). And the expected long bond rate differs from the short rates in any reduction in net supply of long term bonds to the market, as given in (A.13).

The economy is driven by autoregressive forcing processes for spending, $\varepsilon_{s,t}$, cost-push, $\varepsilon_{\pi,t}$, fiscal policy, $\varepsilon_{f,t}$, monetary policy, $\varepsilon_{m,t}$, and quantitative easing, $\varepsilon_{q,t}$. The spending shock simply augments current consumption and hence output, providing some upward pressure on inflation in this model. Cost-push shocks tend to send inflation and output in separate directions. Fiscal and monetary policies feedback from the state of the economy so that we observe higher deficits and lower interest rates when the economy goes into recession. The policy of bond purchasing, or quantitative easing, involves the issuance of money in response to the purchases of long-term bonds. By reducing the relative supply of bonds, this changes the available mix of long and short bonds to agents who prefer short term bonds. It thus induces changes in prices and a reduction in the long term interest

rates. Such policies may be particularly effective if fiscal policy is increasing debt as they will offset an escalating long term premium.

The parameters are defined in Table A1. This illustrative model is solved with standard techniques and allows us to study the paths of endogenous state variables in response to shocks.

Policy experiments

In our policy experiments we explore three simple scenarios. First, we show how a fiscal shock to increase expenditure is mitigated when an active interest rate rule is in place and is amplified under a lower zero bound and QE. Second, we consider whether an active interest rate rule can stabilise a negative spending shock and to what extent QE can provide an adequate substitute. Finally, we consider the implications for exit strategy by considering what happens when QE is reversed in an expansion. In all cases, we run an example shock of a 25% purchase or sale of the initial debt stock by the central bank, which is run down to zero after 10 years. The charts are drawn for the first five years following each shock.

Figure A1 illustrates what happens when the fiscal authority runs a 1% shock to the equation (A.7). Deficit and output increase, putting some upward pressure on inflation and, under the active interest rate rule, some upward pressure on short-term policy rates. Because short and long term interest rates are lower under the zero lower bound (ZLB) with some bond purchases accompanying the fiscal expansion, there is a greater impact from the expansion on output. Hence, any deficit with QE is more expansionary. This means that the debt stock becomes less persistent and returns to the initial level considerably more quickly when a ZLB and QE support the fiscal expansion. Overall, a given fiscal stabilisation measure seems to become more effective when accompanied by QE.

Figure A2 shows what happens when there is a negative spending shock in our economy. This is analogous to a fall in the natural rate of interest or some disruption to the supply of credit to credit-constrained consumers. Interest rates, policy and long term fall, acting to bring consumption quickly back to steady-state. Some impetus is provided by fiscal policy in both cases. The purchase of bonds with a QE-type operation leads to a larger fall in long term rates and actually a smaller overall shock to output. The key point is that a negative shock to consumption can be stabilised well by a combination of QE and an active fiscal rule, even when the active interest rate is switched off.

Figure A3 mimics one possible scenario for exit from quantitative easing in which the central bank is still holding a large debt stock and a recovery is underway. Without any debt sales, interest rates rise in response to the consumption boom and the fiscal authority runs a surplus in order to run down debt stocks. If, on the other hand, the monetary authority embarks on a programme of debt sales, long-

term interest rates rise by more and suppress the output boom to some extent, leading to a smaller surplus and higher debt levels, which will persist. In the first year, we note that policy rates will have to be lower than in the absence of any debt sales. Subsequently – and we have to be careful in drawing too hard a conclusion as the simulations depend on parameter choice and the assumed loss function of the monetary authorities - there is a clear question for monetary policy authorities as to how to return interest rates back to neutral levels without inducing greater output and inflation volatility. This may involve making choices about changing the duration of bond holding by the non-bank financial sector as well as just selling back debt.

It is clear from these simulations that the outcome of stabilisation policies cannot be understood without specifying the fiscal policy response to a shock, and hence the extent to which debt accumulation impacts on long term, and hence average, interest rates. At the ZLB it would appear that the impact of fiscal policy on output is amplified considerably when accompanied by debt sales. And the combination of a ZLB and QE seems to mimic quite well the implied response of policy rates, if they could be lowered below zero, providing we accept that the withdrawal of debt via central bank purchases does have a direct portfolio effect. That said, it is also clear that the use of debt purchases, as a strategy to counteract the ZLB and extreme outcomes, stores up some problems for the future when debt sales may act as a drag on growth. In this sense, given that the amplification to expansionary policy in a recession has the potential to drag growth down in an expansion, any view of the value of these polices must be tempered with the knowledge of their future costs.

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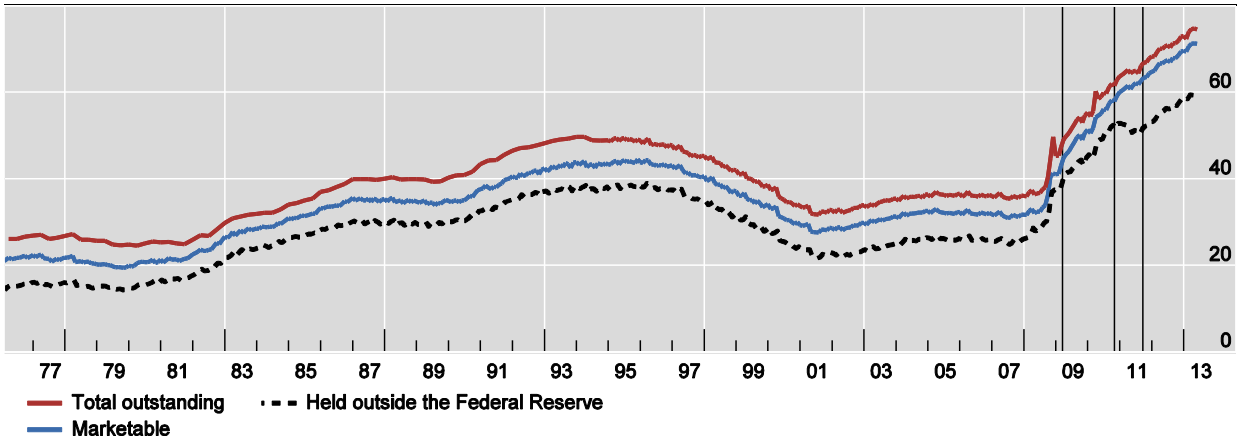
Graphs and tables

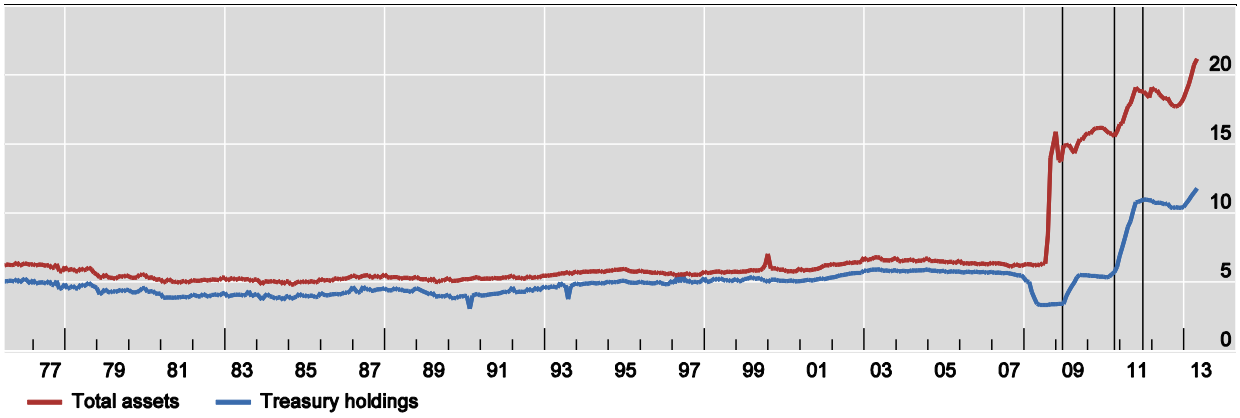
Treasury debt and Federal Reserve holdings (% of GDP)

Holders of US public debt

Graph 1



Balance sheet of the Federal Reserve



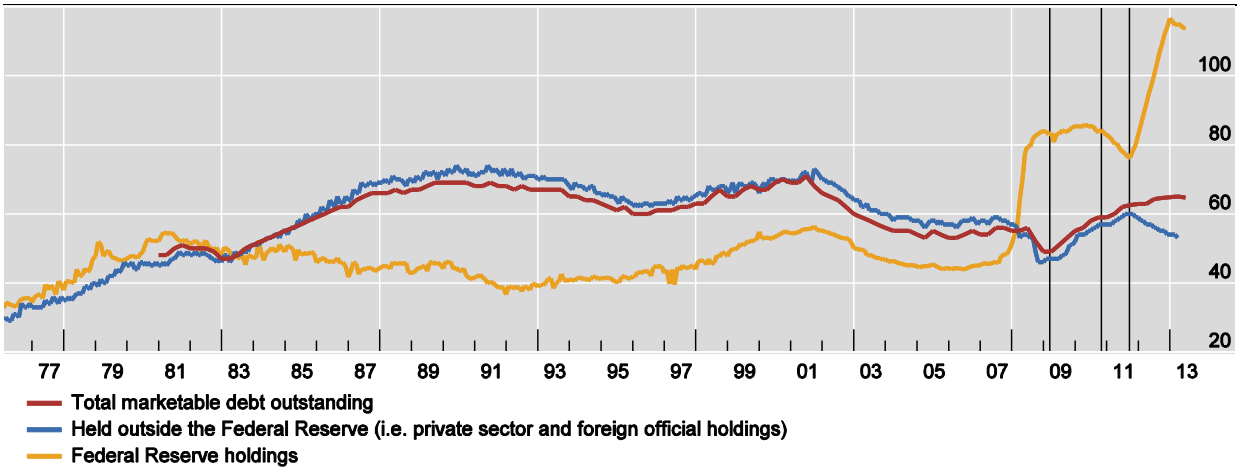
The vertical lines correspond to March 2009 (LSAP1), November 2010 (LSAP2) and September 2011 (MEP).

Sources: Datastream; national data; authors' calculations.

Average maturity of outstanding Treasury debt

In months

Graph 2



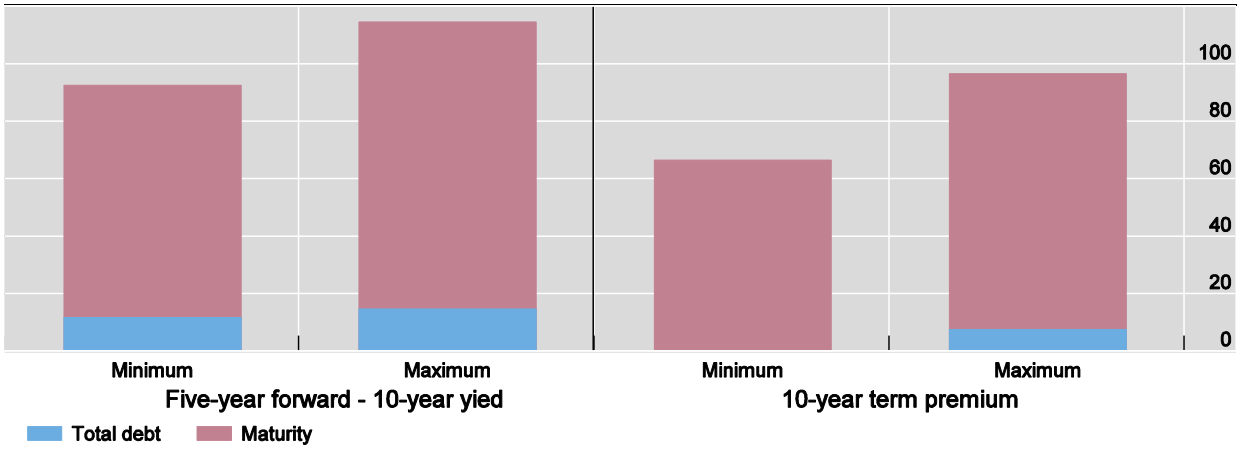
The vertical lines correspond to March 2009 (LSAP1), November 2010 (LSAP2) and September 2011 (MEP).

Sources: US Treasury; authors' calculations.

Predicted effects of Quantitative Easing

In basis points

Graph 3



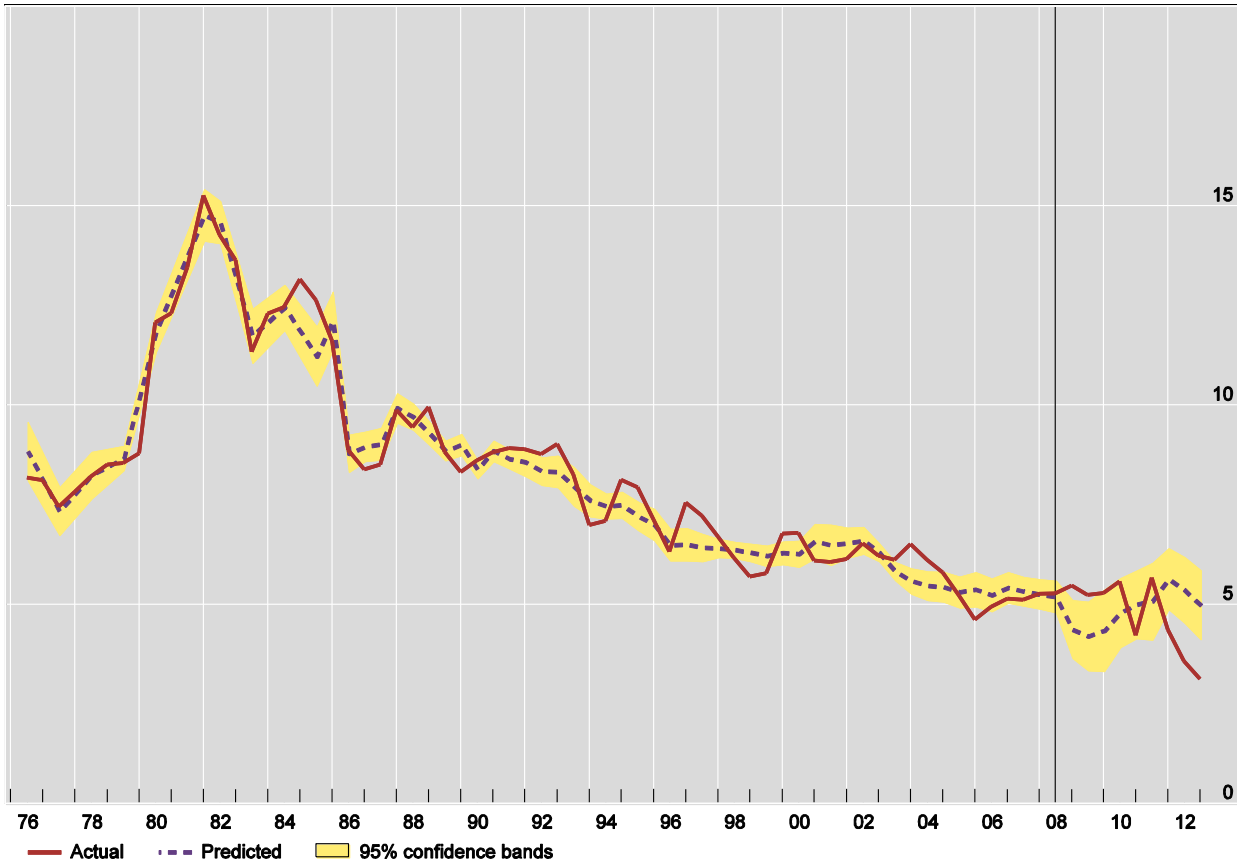
Note: The calculation assumes that since November 2008 debt outside the Federal Reserve has increased by 7 percentage points and that its average maturity has increased by 7 months. For each variable Minimum and Maximum refer to the lowest and largest set of estimated marginal effects of debt and average maturity found across different regression specifications.

Source: Chadha, Turner and Zampolli (2013)

Five-year forward 10-year rate: actual and predicted values[1]

In per cent

Graph 4



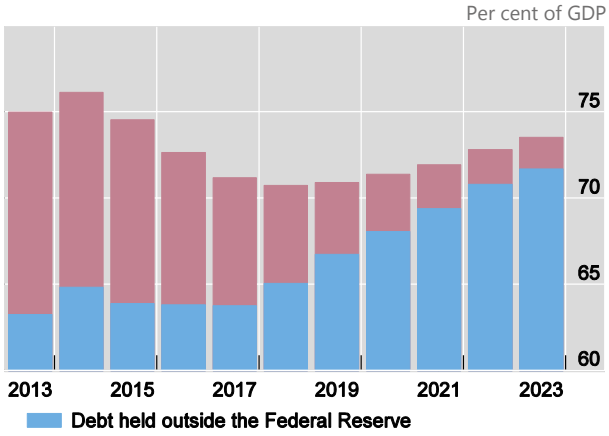
[1] Predicted values are from a regression of the 5-year forward 10-year rate on average maturity of federal debt held outside the Federal Reserve and other regressors. Value to the right of the vertical line are out-of-sample predictions.

Source: Chadha et al (2013).

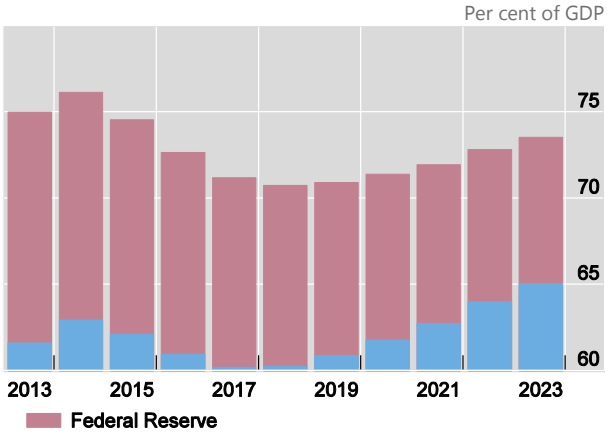
Federal debt projections

Breakdown by main holder — Graph 5

Baseline assumption for Fed[1,2]



Alternative assumption for Fed[1,3]



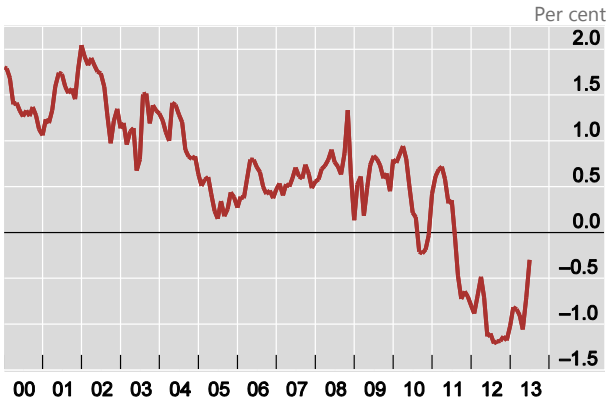
[1] CBO projections under baseline scenario, as of May 2013. [2] Assuming no further purchases by the Fed. Latest purchases taken into account as of end-May 2013; outstanding amounts. [3] Assuming the Fed will purchase $45 billion of US Treasuries from June to September 2013 and reduce the pace of monthly purchases by $5 billion in every consecutive month, i.e. to zero by May 2014 and will keep reinvesting the proceeds from maturing securities after this date, applyng the maturity profile of US Treasury bonds and TIPS outstanding at end-May 2013 and keeping the face value of the portfolio unchanged.

Sources: Congressional Budget Office; Federal Reserve Bank of New York; authors' calculations.

Yields on 10-year US Treasuries

Graph 6

Nominal term premium[1]



Recent turbulence

Note: The vertical line indicates Bernanke's speech on 22 May 2013.

[1] 10-year term premium, based on a joint macroeconomic and term structure model. See P Hördahl, O Tristani and D Vestin, "A joint econometric model of macroeconomic and term structure dynamics", *Journal of Econometrics*, vol 131, 2006, pp 405–44; and P Hördahl and O Tristani, "Inflation risk premia in the term structure of interest rates", *BIS Working Papers*, no 228, May 2007. [2] 20-day moving average of the standard deviation of first differences in the 10-year yield.

Sources: Bloomberg; national data; authors' calculations.

Five-year forward 10-year rate

Table 1

	1976H1-2008H1					1986H2-2008H1	
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Inflation expectation	1.048***	0.999***	1.029***	1.138***	1.006***	1.018***	0.942***
	(0.070)	(0.068)	(0.082)	(0.156)	(0.132)	(0.074)	(0.087)
5-year ahead debt	0.017***	0.021***	0.017**	0.015	0.018**	0.021***	0.017**
	(0.006)	(0.005)	(0.007)	(0.010)	(0.008)	(0.005)	(0.008)
Average maturity	0.121***	0.129***	0.120***	0.132***	0.111***	0.118***	0.116***
	(0.013)	(0.012)	(0.012)	(0.015)	(0.010)	(0.016)	(0.017)
Tbill volatility (t<86H2)	2.997***	2.973***	2.296***				
	(0.250)	(0.257)	(0.442)				
Dividend yield (t<86H2)	-0.934***	-0.802***					
	(0.247)	(0.290)					
Trend growth (t<86H2)	-0.862***						
	(0.289)						
Trend growth					-0.231		-0.140
					(0.280)		(0.250)
Dividend yield					-0.019		0.110
					(0.114)		(0.091)
Tbill volatility					2.232***		0.601
					(0.450)		(0.856)
Observations	56	56	56	56	56	45	45
Adj R2	0.958	0.955	0.948	0.916	0.945	0.910	0.906

Notes: Newey-West standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1. (t<86H2) indicates that a variable is multiplied by a dummy that takes the value of one before 1986H2 and zero thereafter. The regression includes a break dummy (t>=86H2).

10-year term premium 1990H1 - 2008H1 Table 2

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Inflation expectation	0.148	0.139	0.524**	0.024	0.063	0.426**
	(0.346)	(0.303)	(0.235)	(0.315)	(0.225)	(0.200)
Five-year ahead debt	0.012	0.011	0.010			
	(0.008)	(0.007)	(0.007)			
Average maturity	0.115***	0.117***	0.096***	0.126***	0.127***	0.106***
	(0.026)	(0.023)	(0.020)	(0.024)	(0.020)	(0.019)
Trend growth	0.028			-0.064		
	(0.264)			(0.224)		
Dividend yield	0.212	0.220**		0.232*	0.213**	
	(0.133)	(0.102)		(0.121)	(0.093)	
Tbill volatility	0.418			0.407		
	(0.761)			(0.716)		
Five-year ahead deficit				0.093**	0.092***	0.090**
				(0.034)	(0.033)	(0.041)
Observations	37	37	37	37	37	37
Adj R2	0.834	0.843	0.835	0.844	0.853	0.844

Notes: Newey-West standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Marketable Treasury coupon debt securities[1] held outside the Federal Reserve Table 3

US Treasury debt maturity >1-year	Amount held outside the Fed (trillions of dollars)	Average yield[2] (%, pa)	Average maturity (in years)
30 June 2007	2.9	4.77	6.0
31 March 2013	7.8	0.89	5.4

[1] Includes notes, bonds and Treasury inflation-protected securities (TIPS). [2] Based on value-weighted averages of zero coupon yields across various maturity baskets.

Sources: Federal Reserve Bank of New York; Bank of America Merrill Lynch; Treasury Direct.

Appendix Tables:

Table A1
Model Parameter Definitions and Values

Parameter	Value	Description
λ	0.00357	Agents Expect to live until 70
β	0.988	Discount Factor
δ	0.01325	Subjective Discount Rate
γ	0.015	Growth rate in steady-state
$\frac{c}{y}$	0.9	Consumption to output ratio in steady-state
$\frac{m}{w}$	0.3	Money to wealth ratio in steady-state
κ	0.1	Slope of the Phillips Curve
ψ	$=\frac{((1+\lambda)-\beta)}{(1+\lambda)}$	Composite parameter
$\frac{w}{c}$	0.861	Wealth to consumption ratio in steady-state
ϕ_π	1.5	Weight on inf. in Taylor Rule
ϕ_y	0.03	Weight on out. in Taylor Rule
$d\phi_\pi$	0	Weight on inf. in fiscal Rule
$d\phi_y$	1.76	Weight on out. in fiscal Rule
ρ_m	0.21	Weight on lagged short rate
ρ_f	0.57	Weight on lagged deficit
ρ_q	0.95	Weight on lagged asset purch.
δ_1	3	Ratio of Long-to-short bonds
ν	0.1	Elasticity of long-term bonds
σ	6	Money Demand Elasticity
$\frac{m}{b}$	0.42	Money to bonds ratio in steady-state
$\varepsilon_{s,t}$		Spending shock
$\varepsilon_{\pi,t}$		Cost-push inflation shock
$\varepsilon_{m,t}$		Monetary policy shock
$\varepsilon_{f,t}$		Fiscal policy shock
$\varepsilon_{q,t}$		Asset purchase shock
$\varepsilon_{r,t}$		Real interest rate shock

This model can be simulated with MATLAB code available from the authors.

Appendix Figures:

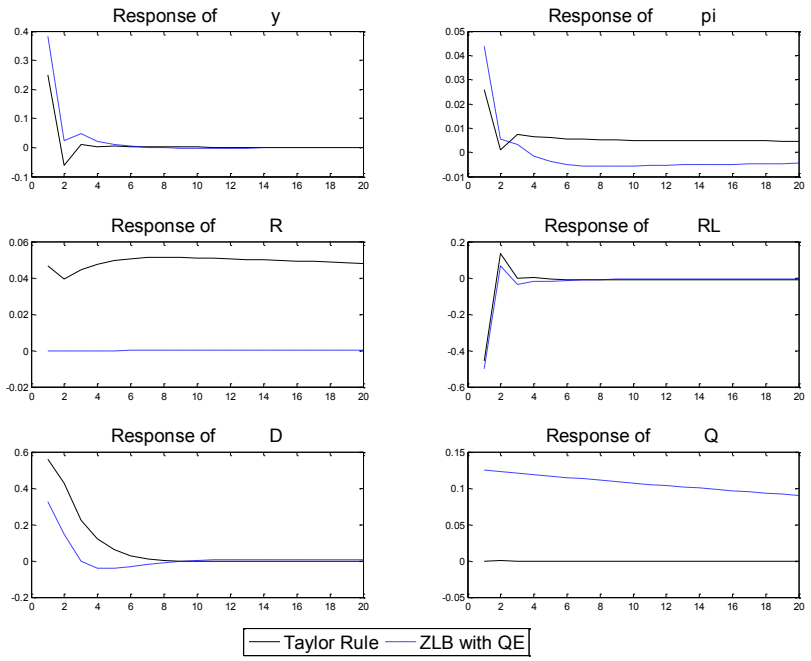


Figure A1: Fiscal Spending Shocks with Taylor Rule and with QE only

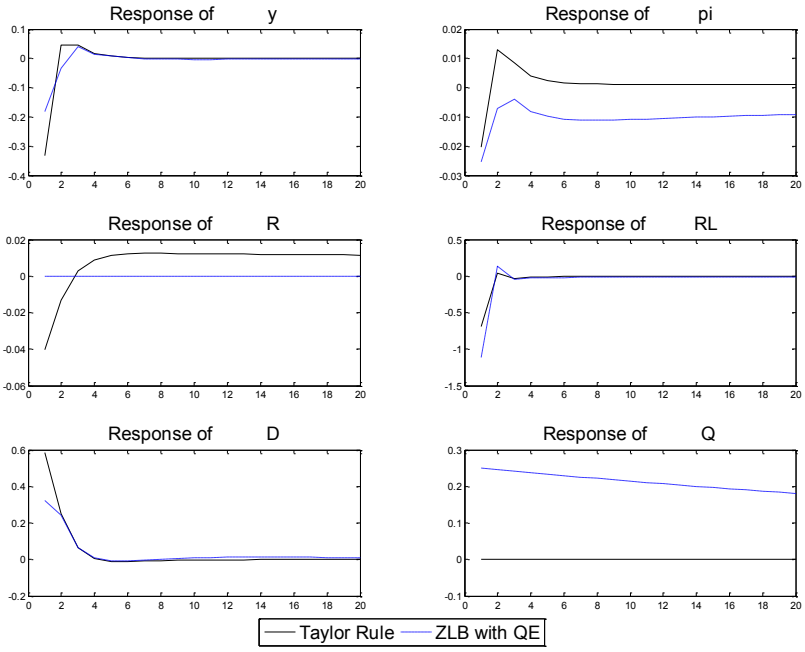


Figure A2: Negative Spending Shock with Taylor Rule and with QE only

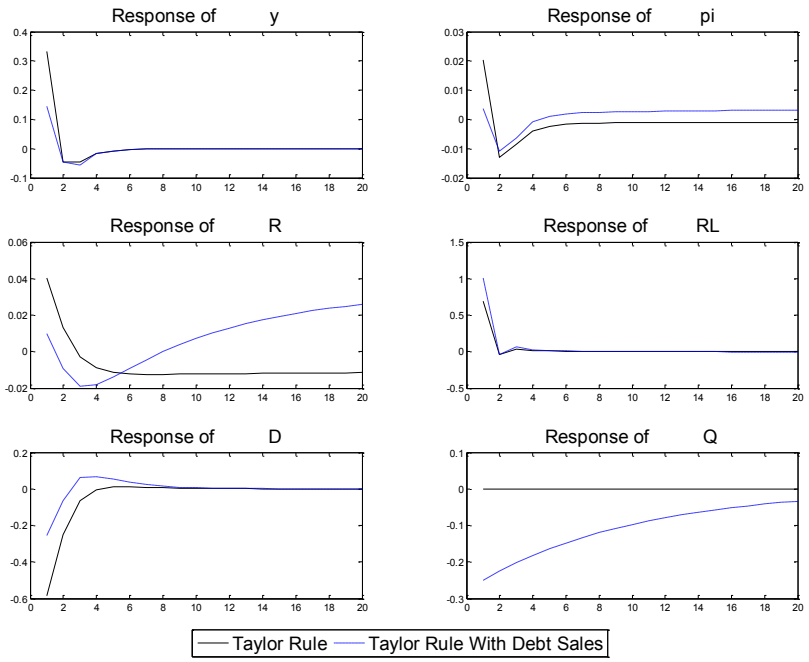


Figure A3: Positive Spending Shock with and without Debt Sales