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The interest rate effects of government debt maturity

Jagjit S Chadha, Philip Turner and Fabrizio Zampolli*

Abstract

Federal Reserve purchases of bonds in recent years have meant that a smaller proportion of long-dated government debt has had to be held by other investors (private sector and foreign official institutions). But the US Treasury has been lengthening the maturity of its issuance at the same time. This paper reports estimates of the impact of these policies on long-term rates using an empirical model that builds on Laubach (2009). Lowering the average maturity of US Treasury debt held outside the Federal Reserve by one year is estimated to reduce the five-year forward 10-year yield by between 130 and 150 basis points. Such estimates assume that the decisions of debt managers are largely exogenous to cyclical interest rate developments; but they could be biased upwards if the issuance policies of debt managers are not exogenous but instead respond to interest rates. Central banks will face uncertainty not only about the true magnitude of maturity effects, but also about the size and concentration of interest rate risk exposures in the financial system. Nor do they know what the fiscal authorities and their debt managers will do as long-term rates change.

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1. Introduction

This paper asks one question of great importance to current monetary policy: "Does the maturity of US Federal debt sold to the market influence the 10-year yield on US Treasuries?" Keynes, Milton Friedman and James Tobin – who shared Keynes's view that portfolio balance effects were important ("Old Keynes") – would have said "yes". But such effects are absent in the standard "New Keynesian" model. Because of highly elastic arbitrage across the yield curve, their argument ran, the relative supplies of short-dated and long-dated debt play no significant role in shaping the yield curve. Large-scale central bank purchases of government bonds since the start of the crisis have given new life to this issue.

It would be tempting to conclude that recent central bank purchases of bonds and very low long-term rates have "proved" the case of "old Keynes". The present state of evidence, however, does not yet warrant such a conclusion. One reason for caution is that the channels through which these purchases work remain uncertain. Buying long-term Treasuries and other assets may simply be viewed as strengthening the central bank's commitment to keeping the policy rate at the near-zero level for a longer period. The longer the public believes that the central bank will keep the Federal funds rate low, the lower long-term interest rates (signalling effect). Yet asset purchases reduce both the amount and the maturity of securities that have to be sold in the market, and thus could also reduce term premia.[1]

A second reason for caution is that most quantitative estimates of the impact of central bank purchases are based on the difficult financial market conditions prevailing in the post-crisis period. Capital constraints on banks and other financial firms, worries about the creditworthiness of wholesale market counterparties and uncertainty about future regulations would all inhibit arbitrage by the private sector. The standard New Keynesian model would not apply in such circumstances – but may again apply in normal conditions.

In order to shed some light on this issue, this paper therefore investigates the empirical relevance of the maturity effects of US Federal debt **over a pre-crisis sample**. Its empirical strategy draws on Laubach (2009), who found significant effects of the prospective budget deficit and prospective debt-to-GDP ratio on forward long-term yields over the period 1976–2006.[2] This analysis is extended by including a measure of Federal debt maturity. In addition, we check that our findings are consistent with those obtained from identical regressions but using an estimate of the long-term term premium (Hördahl and Tristani, 2010) as the dependent variable. Focusing on a period that precedes the start of the crisis improves the chance of identifying the supply effects of federal debt, which would otherwise be obfuscated by current factors that are depressing long-term yields.

[1] If debt securities compete with capital or other forms of financial investment, the private sector will demand a lower premium to hold a smaller supply of securities. Market participants are generally risk averse and face capital constraints so that they might not be willing to fully arbitrage away any price differences between bonds of different maturities.

[2] A key feature of this study is the use of forward long-term rates as well as projected future debt and deficits, which the Congressional Budget Office (CBO) began releasing in 1976. The use of these variables should reduce the downward bias to the estimated effects that arise from countercyclical macroeconomic policies.

The main finding is that a one-month increase in the average maturity of debt outstanding held outside the Federal Reserve is associated with a rise of 12-13 basis points in the five-year forward 10-year rate and a rise of 10-13 basis points in the 10-year term premium. These large estimates are consistent with the existence of significant portfolio balance effects. The logic of such portfolio balance effects seems strong: it rests on the existence of preferred-habitat investors that tend to demand specific maturities and the failure of arbitrage to eliminate price differences across maturities. These are important reasons why changes in the relative supply of public debt do have an impact on term premia (Vayanos and Vila, 2009 and Greenwood and Vayanos, 2010a and 2010b).

One warning about the econometrics of this result has particular relevance for policy. The estimates take decisions on the maturity of debt supplied as **exogenous** with respect to the shape of the yield curve. Assuming exogeneity is a reasonable starting point. Many of the changes in the maturity of debt over our sample were legislated, and so were exogenous to interest rate movements. Nevertheless, such decisions may be partly **endogenous**. Such endogeneity would arise if debt managers were to lengthen the average maturity of outstanding debt when they expected long-term interest rates to be higher in the future and vice versa. In the presence of portfolio balance effects, such decisions to change the maturity would tend to amplify any initial shock to the long-term interest rate (or term premium) and, as a result, the true magnitude of the maturity effect would also tend to be biased upward.[3] [4]

Recent studies that find significant effects of maturity on long-term interest rates (eg Gagnon et al (2010), Greenwood and Vayanos (2010b), D'Amico et al (2012), etc) may also suffer from the same endogeneity problem. In the absence of some explicit modelling of the decisions of debt managers – notably on how they react to changes in the yield curve – doubts remain about the true size of portfolio rebalance effects.

Another interesting finding is that the average maturity of Federal debt makes the inflows into US Treasuries from the foreign official sector superfluous in explaining long-term rates. That is, its coefficient becomes insignificant and close to zero when the average debt maturity is included as an explanatory variable. Without it, the effect of foreign official inflows becomes statistically significant and close to that found by Warnock and Warnock (2009). We interpret this result as indicating that US debt managers have generally accommodated the demand for shorter maturities by foreign central banks, thereby reducing overall average maturity of issuance when these inflows were rising.

A shortening of the maturity of public debt since the early 2000s appears to account for most of the reduction in the observed forward long rate and the term premium. It may also explain what Greenspan called a conundrum (that is, the failure of long-term interest rates to rise in the face of a tightening of the Federal

[3] Annex 3 provides an analytical explanation for the amplifying behaviour of debt managers.

[4] The econometric effect of an increase in the debt-to-GDP ratio is found to be approximately 2 basis points, which is similar to what found by Laubach (2009). The latter author interprets this empirical correlation as the traditional crowding-out effect implied by a standard neo-classical growth model. Another possible interpretation consistent with the existence of maturity effects is that the estimated correlation reflects the possible increase in maturity that accompanies an increase in public debt as managers try to insure against future rollover risks (see Annex 3).

funds rate in 2005). By accommodating the increased demand for shorter maturities, debt managers might have amplified the initial decline in yields brought about by other forces.

The size of maturity effects and the behaviour of debt managers will have important implications for the normalisation of monetary policy. Sales of Treasuries would not only signal that the short-term rate will rise in the future, but they would also have a direct influence on term premia. If so, the ability of the Federal Reserve to control long-term interest rates will depend not only on its own decisions regarding the sales of Treasuries and other assets, but also on the decisions of the fiscal authorities and the debt managers.[5]

In addition to Laubach (2009), our paper is closely related to Greenwood and Vayanos (2010b), who find that the relative supply of long-dated securities is positively related to the yield spreads and subsequent excess returns over short-term yields. Longer maturities were the most affected. Their findings generally support the qualitative predictions of the preferred-habitat and arbitrageurs model of Vayanos and Vila (2009), although their estimated effects on the yield spreads are relatively small and generally have weak statistical significance. Our paper is also related to a number of recent papers that attempt to quantify the effects of Federal Reserve interventions in the bond market since the start of the crisis: these include, for example, Gagnon et al (2010), Doh (2010), D'Amico and King (2012), Meaning and Zhu (2011, 2012), and D'Amico, English, Lopez-Salido and Nelson (2012).[6] Before the crisis Bernanke, Reinhart and Sack (2004) and Kuttner (2006) have also investigated the potential effects of public debt on long-term interest rates. And Swanson (2011) has also recently revisited "Operation Twist" in the 1960s, finding larger effects than earlier studies.[7]

The paper is organised as follows. In section 2 we explain why the relative supply of short-dated and long-dated public debt matters for long-term interest rates. Section 3 provides an account of the operations conducted by the Federal Reserve and its impact on the stock of public debt held outside the Federal Reserve. Section 4 describes the empirical analysis and its results. Section 5 asks whether changes in debt maturity can help to explain the Greenspan conundrum. Section 6 uses the estimates of debt size and maturity to assess the potential impact of Federal Reserve purchases of Treasuries during the crisis. Section 7 outlines a number of possible implications of these results for monetary policy. Section 8 concludes.

[5] Fiscal consolidation in the face of large increases in age-related spending represents a huge challenge for many advanced economies (see Cecchetti, Mohanty and Zampolli, 2010).

[6] Another related paper is Hanson and Stein (2012). Unlike the other papers cited here and our paper, it does not examine the impact of the relative supply of long-term government bonds on long-term interest rates. Instead, it focuses on the demand: commercial banks and primary dealers change the maturity of their government portfolios in response to changes in short-term interest rate expectations, thus affecting term premia.

[7] Missale (2012) discusses the role of debt maturity in ensuring fiscal sustainability.

2. Why the size and the maturity of public debt matter

Portfolio balance effects can explain why both the size and the maturity of public debt matter for the determination of long-term interest rates. Until the mid-1980s, the prevailing orthodoxy among economists followed Keynes, Tobin and Milton Friedman in viewing portfolio effects as key to understanding how monetary policy worked. From the late 1980s to the onset of the crisis, however, many monetary economists had come to view portfolio rebalancing effects as irrelevant or empirically too small to justify their inclusion in formal models of monetary policy. Indeed, in the standard New Keynesian model all that matters for demand determination of aggregate demand is the path of current and future short-term interest rates. In this stylised framework, changes in the relative supplies of financial instruments, including money and government debt, have no role in shaping the yield curve (Eggertsson and Woodford, 2003). But the crisis has demonstrated the important role that quantities such as money, debt and credit can play in monetary policy.

The balance sheet policies pursued by central banks since the recent crisis, however, would be effective only if – contrary to the standard New Keynesian framework – portfolio balance effects are significant. The measurement of, and finding better foundations for, portfolio rebalancing effects has therefore become a top research priority. This is needed to clarify the effectiveness, the limits and risks of the policies that central banks, financial regulators and fiscal authorities have adopted.[8] One promising avenue is the development of investors' preferred habitat theory within a modern model of the yield curve. The preferred habitat hypothesis, originally proposed by Culbertson (1957) and Modigliani and Sutch (1966, 1967), has recently been formalised by Vayanos and Vila (2009).[9] The theory combines two ingredients. The first is the existence of heterogeneous preferences about the maturities that some agents want to hold. For example, pension funds may be keen to "lock in" a long-term interest rate for their assets. Or they may face regulatory restrictions that require them to match their asset duration to that of their liabilities. The second ingredient is the ability of arbitrageurs to undertake maturity transformation across the yield curve, which depends, among other things, on their risk aversion and their capital.

If the theory is correct, increasing the maturity of public debt should raise long-term interest rates relative to the path of future short-term rates.[10] The initial effect of an expansion in the supply of long-term bonds, given unchanged demand, is that bond prices would fall. Arbitrageurs would then buy the cheaper long-term bonds (reversing part of the initial decline) in exchange of short-term bonds (whose price would rise). The initial gap in prices would not be eliminated completely

8 See eg Zampolli (2012) for an overview.

9 Hamilton and Wu (2012) has provided a discrete-time formulation of the preferred-habitat model of Vila and Vayanos (2009) and used it to estimate the impact of recent quantitative easing in the United States. They find that supply has an impact, although their estimates are on the lower range of the literature.

10 These effects require a failure of Ricardian equivalence; otherwise, private agents would simply buy any additional amount of bonds issued by the government with no need for interest rates to induce such behaviour. However, borrowing, liquidity and informational constraints, among others, are important factors that make non-Ricardian effects quantitatively important.

because arbitrageurs demand a risk premium to cover the interest rate risk from holding a larger stock of long-term bonds. Their ability and willingness to bear this risk may also vary over time.

The important point to note is that the effect of lengthening debt maturity is to raise all interest rates, including the short-term ones. This may seem surprising given that an increase in maturity should lead to a relative scarcity of short-term bonds (and possibly even to a reduction in their yield). In fact, as pointed out by Greenwood and Vayanos (2010b), the larger exposure to interest rate risk of arbitrageurs raises the market price of short rate risk. This in turn affects bonds of all maturities, albeit the shorter ones by less. For sufficiently low levels of arbitrageurs' risk aversion, changes in the market price of short rate risk dominate the effects of local demand and supply conditions.[11] [12]

3. Central bank purchases and government debt issuance policies

The monetary implications of decisions about the size and structure of government debt issuance and decisions about central bank purchases of government debt are virtually identical.[13] Hence central bank purchases of bonds must be analysed in the wider context of government debt issuance policies. The macroeconomic implications of both policies will depend on the nature of fiscal policy.

Since the beginning of this crisis, sovereign debt management has often worked in apparent conflict with the objectives of monetary policy (Blommestein and Turner, 2012, and OECD, 2013). On the one hand, central banks were purchasing government and other longer-dated securities with the goal of enhancing market liquidity conditions and lowering longer-term interest rates. On

[11] Consistently with the theory, these authors 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. Evidence that the supply of public debt influences interest rates has been provided before the crisis by eg Bernanke, Reinhart and Sack (2004), Kuttner (2006). The effects of central bank non-standard policies are estimated in eg Gagnon et al (2010), Doh (2010), D'Amico and King (2012) and D'Amico, English, Lopez-Salido and Nelson (2012). Swanson (2011) revisits the effects of "Operation Twist" in the 1960s.

[12] An additional consequence of raising public debt maturity is to increase private money creation, potentially leading to greater financial stability risks (Greenwood, Hanson and Stein (2010)). For example, it has been argued that, besides regulatory arbitrage, a reason for the huge expansion of the shadow banking sector prior to the crisis, was a shortage of safe short-term assets relative to the demand of institutional investors and corporates. As a result, repos and asset-backed commercial papers flourished (Poszar, 2011) but, as it became clear in hindsight, the financial system grew much more fragile as well. Consistent with this hypothesis, Krishnamurthy and Vissing-Jorgensen (2010) find that public debt is inversely related to measures of private money. It would seem that if financial regulation and supervision are not enough to control the creation of privately-created liquid assets, authorities could issue more short-term debt. However, if portfolio rebalancing effects are significant, a reduction of public debt maturity may also reduce the long-term interest rate and stimulate asset prices. It is therefore unclear whether tilting public debt issuance towards shorter maturities would actually mitigate financial stability risks.

[13] The main qualification to this is the differing impact on expectations. Central banks, with their purchases, can also influence expectations of their future decisions about the policy rate or additional purchases. They may therefore have more leverage on interest rates than the debt managers. But actions should first be judged on the basis of how they affect the portfolios of those agents who have to be induced, in the open market, to buy bonds.

the other hand, the debt managers were taking advantage of the strong recession-induced demand for government bonds to significantly extend the maturity of Federal government debt issuance.

As a first approximation, what should matter for the determination of long-term interest rates is the net supply of government debt to the market, and not how much debt the central bank is holding on its balance sheet. Hence, in this section we first review the purchases of government bonds conducted by the Federal Reserve; we then examine how such central bank operations have changed the maturity and size of the public debt held outside the central bank.

3.1 Central bank large-scale purchases of bonds

The Federal Reserve engaged in four rounds of large-scale asset purchases (LSAPs). In the first round, which is also referred to as Quantitative Easing 1 (or QE1), the central bank bought some $1.75 trillion of assets over the period November 2008 – March 2010. It first announced on 25 November 2008 that it would buy $600 billion of MBS and agency debt. Then, on 18 March 2009, it announced that it would purchase another $850 billion of agency debt plus $300 billion (or 2.2% of 2009 GDP) of Treasury securities.

In the second round, also known as QE2 and announced between August and November 2010, the Federal Reserve purchased about $600 billion of Treasury bonds 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) in Treasury securities of 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 conducted by the Federal Reserve 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 addition, the Federal Reserve also decided to maintain unchanged the size of its MBS portfolio by reinvesting proceeds from its MBS into purchases of MBS.

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. In December 2012, this scheme was extended to include the additional purchase of $45 billion of Treasuries per month.

3.2 The size and maturity composition of non-central-bank held public debt

How did the total size and maturity structure of the public debt held outside the Federal Reserve change as a result of central bank purchases? The dashed line in Graph 1 shows the size of US Treasury debt held outside the Federal Reserve.[14] Before 2008, this moved in parallel with total marketable US Treasuries outstanding. But from 2008, these lines diverged: almost a fifth of the increase in the outstanding stock of marketable Federal government debt since mid-2008 was absorbed by the Federal Reserve.

The maturity composition of outstanding Federal debt is shown by ascending maturity brackets (the dark blue shading showing maturities less than one year, the yellow shading showing maturities between one and five years and so on) in Graph 2. A summary measure is provided by the average maturity shown in Graph 3. This graph shows that the average maturity of Federal Reserve holdings (yellow line) after the mid-1980s tended to decline gradually as the maturity of total debt rose. From the mid-1990s until the beginning of the crisis, it tended to track that of total debt (red line). This was a period in which the Federal Reserve clearly did not attempt to use its own balance sheet directly to influence long-term interest rates. Note that the maturity of outstanding US Treasuries shortened significantly from early 2001 to 2006.

Central bank operations in the Treasury market assumed much greater importance following the crisis. In the second half of 2008, short-term debt (of less than one year maturity) shot up by 8 percentage points to 20 per cent of GDP. This mostly reflected the large special issuance of Treasury bills under the Supplementary Financing Program (SFP) introduced at the request of the Federal Reserve immediately after the collapse of Lehman Brothers.[15] As the fiscal deficit widened towards the end of 2008, the Treasury started issuing larger amounts of debt. At the same time, the Treasury began to lengthen the average maturity of government debt issuance (Graph 3).

Up until late 2008, the Federal Reserve had held its aggregate balance sheet constant, reducing its holding of Treasuries, especially bills and intermediate maturities, to finance its various liquidity provision programmes (lower panel of Graph 1). Thereafter, the Federal Reserve balance sheet expanded massively and the maturity of its debt holdings shifted towards longer-term maturities. With these actions, the Federal Reserve reduced the increase in debt at various maturities that the private sector or foreign official investors would otherwise have to absorb. In particular, QE2 halted or slowed the increase of debt held outside the Federal Reserve. Nevertheless, government debt outstanding in the market is high by historical standards: debt of one to five-year residual maturity at more than 20 per

[14] The difference between the two represents the total holding of federal debt by the Federal Reserve. Prior to the crisis, Federal Reserve holdings of Treasuries remained relatively small, growing slightly from the mid-1980s till the outset of the crisis. Such a rise mirrors the increase in the balance sheet of the Federal Reserve and has been driven mainly by an increase in the demand for currency (not shown here).

[15] The purpose of the SFP was to drain the bank reserves created by various liquidity programmes initiated at that point of the crisis to reduce market stresses, enabling the Federal Reserve to maintain control of the Federal funds rate. Soon after the Federal funds rate was reduced to near zero levels, and the SFP was rapidly scaled back. See, eg Hrung and Seligman (2011) for a description of the SFP programme and its impact on the repo market.

cent of GDP is well above the peak reached in the mid-1990s; and debt of five to 10-year residual maturity is double what it was just before the crisis.

4. Empirical evidence

This section provides new evidence about the effects of Federal government debt and its maturity on US long-term interest rates by extending the well-known analysis of Laubach (2009) to incorporate maturity effects. Our analysis differs from other studies in two main ways.

First, our focus is on the size as well as the maturity structure of government debt held outside the central bank, which can be affected by the operation of both the central bank and the fiscal agency. The aim is to estimate portfolio rebalancing effects in "normal times" before the crisis struck and before the Federal Reserve started intervening massively. The estimation period therefore only covers the pre-crisis period during which the central bank was not seeking to influence long-term interest rates directly – that is, over and above the effects of future expected short-term interest rates. These estimates should not be contaminated by the special effects of recent central bank intervention, regulatory changes and safe-haven flows on long-term interest rates.

Second, measures of *expectations* of future variables (**not** the current readings) are used whenever available. Interest rates and fiscal deficits may be negatively correlated over the business cycle because of the operation of the automatic stabilisers or systematic discretionary stimulus. Hence, regressions of interest rates on current levels of deficit or debt may lead to estimates that are biased downward or even statistically insignificant. This problem was pervasive in the earlier empirical literature on the interest rate effects of fiscal policy, and led some to conclude, too hastily, that the results were consistent with Ricardian equivalence.

As Laubach (2009), our analysis focuses on the five-year-forward 10-year maturity interest rate, which should be less influenced by the business cycle and monetary policy. And we capture future expectations of fiscal variables by using the 5-year ahead projections for the budget deficit and the debt released twice a year by the United States Congressional Budget Office (CBO). We also consider an estimate of the 10-year term premium (Hördahl and Tristani, 2010). By construction, this estimate excludes the expected future short-term rate. Such estimates, being model dependent, are of course uncertain.

4.1. Empirical specification

We take as a starting point in our analysis the empirical specification suggested by Laubach (2009), to which we add a measure of the maturity structure of the public debt as well as additional control variables. Our specification is as follows:

$$f = \alpha\pi^e + \beta g^e + \delta d^e + \gamma m + \phi X + \varepsilon \qquad (4.1)$$

where f is the forward rate or the term premium, π^e is a measure of long-term inflation expectations, g^e is a measure of future expected real output growth (or trend growth), d^e is a measure of expected future fiscal policy (either the debt-to-GDP ratio or the fiscal deficit), m is a measure of the average maturity of debt held outside the Federal Reserve, X is a list of other control variables and ε is an error.

4.2 Data description

Our dataset builds on that of Laubach (2009), which starts in 1976 when the CBO projections become available and runs until mid-2006. We have extended it to include the most recent observations as well as additional control variables.

The measure of inflation is the survey of long-horizon inflation expectations by market participants and professional forecasters (published by the Federal Reserve Bank of Philadelphia). The measures of expected future output growth, public debt and deficits are all 5-year-ahead projections of the respective variables published twice a year by the CBO.[16]

The main focus of our analysis is the measure of the maturity structure of public debt, a variable that had not been considered in Laubach (2009). We use the average maturity of federal debt held outside the central bank expressed in months.[17]

The list of control variables includes a measure of risk appetite as well as a measure of interest rate uncertainty. Specifically, following Laubach (2009), we control for the stock market dividend yield on the assumption that investors who become more risk averse shift their portfolios away from equity and towards government bonds, thereby leading to a rise in the dividend yield and a corresponding fall in the bond rate. As a measure of interest rate risk, we take the 12-month rolling standard deviation of the 3-month Treasury bill rate.[18] Furthermore, to control for the effects of the business cycle, we follow Laubach (2009) and consider the three-month Treasury bill rate and the real-time output gap of Orphanides (2003).[19] We also check that our results are not driven either by domestic or by foreign central bank operations. That is, we also control for the total holdings of Treasuries by the Federal Reserve and for purchases by the foreign official sector.[20]

16 Since 1985 the CBO has regularly released its projections twice a year. Hence, our sample is made up of half-yearly observations. Before 1985, its projections were published most of the time with yearly frequency and occasionally twice a year. This means that there are gaps in the early part of our sample.

17 Table FD5 in the US Treasury Bulletin (www.fms.treas.gov/bulletin/b2012_4fd.doc).

18 We also considered other measures of risk aversion such as the residuals from the consumption model of Lettau and Ludvigson (2001), which are used in Laubach (2009). We also considered different measures of interest rate risk such as the volatility of long-term interest rates calculated, like in Warnock and Warnock (2009), as the rolling 36-month standard deviation of changes in long rates; the realised standard deviation of the SP500 return and the VIX index (available only as of 1986). In a preliminary investigation these variables generally did not turn out to be significant or did not lead to well-specified models).

19 This is also taken from Laubach's database (2009) and is constructed using real-time estimates from the Federal Reserve Board staff before 1997 and CBO estimates after 1997.

20 Official inflows into US Treasuries are taken from TIC data and are available only as of 1978. We take a one-year rolling average and scaled it by potential GDP, rather than actual GDP, to minimise the chance of business cycle fluctuations spuriously affecting the estimates. We also scale Federal Reserve holdings of Treasuries by potential GDP.

4.3 Estimation method and properties of the data

We estimate equation (4.1) by OLS. Given that the errors exhibit serial correlation, we compute and report Newey-West standard errors. We assume error serial correlation of lag three. Preliminary investigation has revealed that the univariate AR model that best fits the errors has generally three lags, which is sufficiently large to allow for quite general processes governing the residuals. Regardless, our estimation results are generally robust to changes in the lag. Before proceeding to the discussion of the results, three potential problems need to be addressed: stationarity; endogeneity of the regressors; and estimate instability.

(a) Stationarity

The first is that both the dependent variables and the regressors may not be stationary. Indeed, measures of long-term interest rates have been declining since the early 1980s along with inflation and inflation expectations. Other variables among the regressors also seem to exhibit non-stationary behaviour. In this regard, Laubach (2009) has shown that the five-year ahead 10-year interest rate used in our analysis is cointegrated with expected long-term inflation and that adding the fiscal variables do not alter this conclusion.

Both the data in Laubach (2009) and in our analysis are of the same frequency and cover a similar sample. Nevertheless, we also carried out some unit root and cointegration tests. Annex 1 provides the details. For the interest rate variables and inflation expectations the tests generally point to the presence of a unit root. For the fiscal variables the evidence is more mixed. Cointegration tests generally support the assumption that interest rates are cointegrated with inflation expectations even when fiscal variables are added to the basic regression.

It is important to note that in small samples such as ours there is no sure way of distinguishing between a series exhibiting a unit root and a stationary one with a high degree of persistence. That is, the tests have very low power and cannot be relied upon entirely. In our view, plots of the series and judgment, along with the tests, support the hypotheses on which the regressions are based.

(b) Endogeneity of the regressors

The second potential problem is the endogeneity of the regressors. In particular, the maturity structure, which is the main focus of our analysis, may not be exogenous to macroeconomic developments. Several authors (eg Kuttner (2006), Gagnon et al (2010)) have suggested that OLS estimates of regressions of yields or spreads should be biased downward, thereby offering a conservative estimate of the true portfolio rebalancing effects of public debt. However, it is unclear that this is necessarily the case if debt managers are forward looking and take into account the possible future evolution of long-term yields or term premia. For example, rational sovereign debt managers aiming at reducing debt servicing costs could raise the maturity of issuance today when future long-term rates are expected to be higher, and vice versa.[21] Annex 3 offers a very simple model to look at the issue. It shows

[21] Hoogduin, Öztürk and Wierts (2011) report evidence that euro area countries increase the share of short-term debt when the short-term interest rate falls. Blommestein and Turner (2012) showed that US debt issuance tends to shorten when the Federal funds rate falls.

that debt managers may amplify the fluctuations of long-term interest rates following a shock. If so, the OLS estimates would be biased upward.

Nevertheless, it is not clear a priori that any endogeneity bias should necessarily be large. One reason is that some of the changes in the maturity structure of the public debt over our sample are clearly driven by changes in legislation. For example, at the start of our sample in 1976 the Congress lifted the 4¼% ceiling on the coupon that could be offered on 10-year Treasuries – in effect allowing the issuance of 10-year bonds, which led to a gradual increase in average maturity in the following years. Later, following several years of large fiscal surpluses in the second half of 1990s, the Treasury undertook a number of buyback operations between 2000 and 2002. As short-term notes were expiring without being replaced by new issuance, the average maturity rose. The buyback operations were decided to bring average maturity down. In 2001 the Treasury also discontinued the issue of the 30-year bond.[22]

Another reason why the endogeneity bias may be small is that we focus on the forward long-term rate and the term premium, which should not be much influenced by the short-term interest rate. To the extent that debt managers issue longer-term debt in response to a narrowing of the yield spread, we would expect the endogeneity bias to be smaller in regressions in which the short-term rate, and hence the yield spread, does not play a relevant role.

(c) Instability of estimates

The third potential problem is the instability of the estimates across the sample period, which runs from 1976 to 2011 and hence covers different monetary and fiscal policy regimes. Estimates may vary too much across different subsamples, thus mislead about the true size of the effects. To minimise this risk, we carried out some preliminary structural break analysis. Namely, we assume that all coefficients except that of inflation expectations (including the intercept) in our baseline specification could be subject to a structural break at an unknown date.[23] By varying the possible break date, we compute a sequence of F statistics on the break coefficients, which can then be used to construct a test for the existence of a structural break within the sample.[24] Given the possible presence of heteroscedastic errors, we rely on minimising the residual variance to identify the date at which the break occurs. We first find strong evidence of a break in the first half of 1986. Repeating the test procedure over the split sample, we find another clear break in the second half of 2008, corresponding to the most acute phase of the financial crisis. We therefore proceed to present results for the pre-crisis sample 1976H1–2008H1 taking into account the break in 1986H1.

[22] See eg Garbade and Rutherford (2007).

[23] Our baseline specification includes long-term inflation expectation, expected growth, the dividend yield, interest rate volatility, expected debt, average maturity. Given the assumption that the forward rate is cointegrated with inflation expectation we maintained the assumption that this latter variable has no structural break. However, we also checked the existence of a break in inflation expectations and found no evidence for it.

[24] The test statistics that we consider are: the largest value of the F statistic (the Quandt or SupF statistic); and the ExpF and the AvgF statistics suggested by Andrews and Ploberger (1994). Approximate p values for these statistics are provided by Hansen (1997). Hansen (2001) provides a non-technical review of the techniques for detecting structural breaks. We also vary the set of coefficients assumed to be subject to a structural break obtaining consistent results.

4.4. Results

In what follows we present two sets of results which differ in the dependent variable used in the regression. The first set concerns the five-year-forward 10-year interest rate while the second set regards the 10-year term premium.

(a) Five-year forward 10-year interest rates

The structural break analysis leads to the estimation of a general specification (shown in Annex Table A4) in which all coefficients but inflation expectations are allowed to change at the selected break date of 1986H2. The examination of this equation suggests that the coefficients of expected debt and average maturity remain constant before and after the break date, whereas those of the other variables do change. In particular, expected future growth, the dividend yield and the short-term interest rate volatility turn out to be significant only before the break date (t<86H2) and statistically insignificant thereafter (t>=86H2). The validity of these restrictions is also confirmed by an F test (see the bottom of Annex Table A4). The shift in the intercept is strongly significant, capturing the unusually high interest rate levels in the early part of the sample, which cannot be completely explained by changes in the explanatory variables (and for which it is hard to find other satisfactory explanatory variables).

The tested-down version of the previous equation is shown in the first column of Table 1. With one exception, all coefficients in column 1 have the expected sign and appear of reasonable size:

- A one percentage rise in long-horizon inflation expectations adds about one percentage point to the 10-year yield.
- A one percentage point rise in the debt-to-GDP ratio five years 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 as well as in his calibration of a small neoclassical growth model.
- Greater volatility in the short-term rate drives up the long-term rate.
- Greater risk aversion (as proxied by the dividend yield) drives down long-term interest rates.

The one exception is the five-year-ahead output growth rate (our proxy for trend growth): this variable has a negative sign and a large magnitude, which appears at odds with economic theory. The good news is that this variable is unrelated to the other regressors: when it is dropped the estimated coefficients of the other variables are very little changed and the loss of fit of the model (measured by the adjusted R-squared) is minimal (Column 2). The most plausible explanation is that CBO projections for output five years ahead are not a good proxy for trend growth. For example, a negative sign may be an indication that forecasters were projecting future trend growth on the basis of current macroeconomic conditions including the long-term interest rate, downgrading future trend growth when interest rate were unusually high, other things equal. Further investigation reveals that trend growth appears to be negatively correlated with the forward rate in the early part of the sample. When we re-run the regression from 1980 (not shown here), thus excluding this early part of the sample, we find that the coefficient on trend growth becomes positive albeit statistically insignificant. Hence we conclude that the negative and significant coefficient on trend growth is very likely to reflect an artefact of the data. We therefore regard the regression in Column 2 as our baseline case.

Public debt and its maturity are significantly and positively associated with the forward long-term interest rate. 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 as well as in his calibration of a small neoclassical growth model. Lengthening the maturity of public debt (held outside the Federal Reserve) by one month is associated with a rise of between 12 and 13 basis points (the 95% confidence interval is from 11 to 15 basis points). This is equivalent, other things equal, to a rise in the forward rate of almost 150 basis points for each year of increase in the average maturity.

The effects of maturity are robust to dropping the dividend yield (Column 3) as well as interest rate volatility (Column 4), although in the latter case the effect of debt becomes slightly smaller and statistically insignificant. This shows that controlling for the volatility of short-term interest rate in the early part of the sample is necessary to identify the effects of debt. Column 5 shows that the results remain robust even if a break is not allowed in the control variables (although of course the fit of the model diminishes). In this case, the dividend yield is statistically insignificant and expected future growth continues to have a negative but statistically insignificant coefficient.[25]

Finally, the results concerning the debt and its maturity are robust to re-estimating the regression over the post-break period 1986H2-2008H1 (Column 6). Note that when we add the control variables, these turn out to be statistically insignificant (Column 7), thereby confirming previous results about the existence of a break in the coefficients associated with these set of variables.

Further robustness checks are shown in Table 2. Regressions in this table control for the business cycle, the total holdings of Treasuries of the Federal Reserve, and the foreign official sector purchases of US Treasuries. For ease of comparison Column 1 in Table 2 reports our baseline regression (corresponding to Column 2 in Table 1). Both the short-term interest rate (Column 2 in Table 2) and the real-time output gap (Column 3 in Table 2) have no effect on the forward rate and cause very little change in the other coefficients.

When Federal Reserve holdings of Treasuries are added, it is also found to be statistically insignificant – that is, once account is taken of changes in the maturity of Treasuries outside the central bank (Column 4). Interestingly, however, when maturity is dropped from the regression, Federal Reserve holdings of Treasuries (which approximate the size of the their balance sheet before the crisis) has a strong negative, and statistically significant, effect on the forward rate (Column 5). However, there is no plausible explanation in our view for a causal link running from their balance sheet to the forward long-term rate for the sample period of our regressions. Indeed, from the early 1980s to the beginning of the financial crisis, the Federal Reserve had been expanding the size of its balance sheet, in response to a higher demand for currency (which was rising more rapidly than nominal GDP) at

[25] Laubach (2009) finds that trend growth has a negative but statistically insignificant coefficient. So, when we do not allow for breaks in the sample our results about trend growth are consistent with his.

the same time as long-term interest rates and expected inflation were falling. Controlling for the maturity of public debt held by the private sector – which is affected by the central bank operations – eliminates this spurious and counterintuitive effect.

When we add foreign official purchases of Treasuries (Column 6), we find that this variable is statistically insignificant.[26] When average maturity is dropped, the effect of official inflows becomes negative and statistically significant and its magnitude is similar to the one found by Warnock and Warnock (2009). These authors estimate that an increase of about 2 percentage points of (lagged) GDP in 2004 contributed to reducing the 10-year interest rate by some 80 basis points. Our estimate leads to a similar conclusion: expressed in terms of potential GDP, inflows in 2004 peaked at 1.77%, which multiplied by our estimate of –0.522 leads to a negative contribution of about 90 basis points. The crucial point, however, is that we find this result when we do not control for public debt maturity.[27]

Our findings are consistent with the idea that debt managers may have varied the maturity structure of public debt in partial response to the preferences of foreign official investors for shorter maturities. Of course, average maturity could capture not only the accommodation of rising foreign official inflows but possibly also domestic factors, including the accommodation of an increasing demand for more liquid assets arising from an expanding and leveraging financial system.[28]

(b) 10-year term premium

The term premium is the part of long-term interest rate that is not affected by the expected future short-term interest rate. As such, it offers a useful cross-check on the estimates obtained using the forward rate. Table 3 shows regressions that employ the term premium estimated by Hördahl and Tristani (2010) as the dependent variable. Given data availability, our sample starts in 1990.[29]

Our baseline equation (Column 1) includes trend growth, the dividend yield and the volatility of Treasury bill rates as control variables in addition to five-year ahead debt and average maturity. Columns 2 and 3 report the same regressions dropping some of the insignificant control variables. Note that long-term inflation

26 Note that the series of official sector inflows into Treasuries is available as of 1978. Given that we are using a 12-month moving average, the first available observation is 1979H1. Taking into account the gaps in the data due to the irregular releases of the CBO, the estimation sample has now three fewer observations.

27 The results shown in Warnock and Warnock (2009) are based on a different sample period (1985–2005) and on monthly frequency. In addition, the dependent variable is the spot 10-year rate instead of the forward rate; foreign inflows are scaled by lagged GDP rather than potential GDP; and the set of other regressors also differs. We downloaded the dataset used in Warnock and Warnock (2009) and tried to replicate their results using the average maturity of privately-held public debt (at monthly frequency) as an additional control variable. In this case we also found that the official inflows are no longer significant while average maturity is.

28 Using the five-year forward five-year interest rate as well as the 10-year forward five-year rate as dependent variables gives estimates of the effects of debt and its average maturity which are very similar to the ones shown in Table 1 (details available on request).

29 According to this model-based calculation the term premium has been around -100 basis points since early 2012. Part of this unusual negative reading, however, reflects an exceptional flight-to-quality or a flight-to-liquidity after the crisis. Chadha (2012) shows that such effects have been important historically.

expectations are generally not significant. This is consistent with the relative stability of inflation enjoyed by the US economy since the 1990s. Furthermore, the effect of debt is statistically insignificant. For this reason, we also run regressions with the CBO five-year ahead projection of budget deficit in place of the five-year ahead debt (Columns 4–6). This is statistically significant and shows that a one percentage point increase in the expected deficit leads to 9 basis point rise in the term premium.

Another noticeable finding is that, perhaps surprisingly, the dividend yield is positively correlated with the term premium. Following Laubach (2009), we took this variable as a proxy for investors' risk aversion. In fact, over the sample period that starts in 1990, the positive correlation of this variable seems consistent with investors shifting their portfolios towards equities on the wake of a positive dividend growth expectation. Given competing higher returns from equities, bond investors would have required a larger premium to stick to government bonds.

Across different specifications the effect of average maturity is between 10 and 13 basis points, which is in the ball park of what was found in regressions of the five-year forward 10-year rate. The fact that we find similar estimates suggests that the estimated effects on the forward rate mostly reflect changes in the term premium.

(c) How does the model fit data during the crisis?

It is interesting to assess how the empirical model fits actual data during the crisis period. Table 4 summarises recent readings of the key variables. The 5-year forward 10-year yield has fallen from a range of 5 to 5½% in the pre-crisis years to 3 to 3½% since the beginning of 2012. Despite a severe recession and much talk of deflation risks, long-term inflation expectations have fallen only slightly (if at all). The near-zero policy rate and forward guidance has reduced the volatility of the short-term interest rate, but this was already low.

Graph 4 shows the five-year forward 10-year rate along with the predicted values from the respective baseline regressions. In the first stage of the crisis the forward rate was significantly above what the model predicts. The strength of liquidation forces may well explain why rates did not decline. The strong demand for liquidity in that period was met by several large Federal Reserve programmes.

In the subsequent stage of the crisis (that is, from the end of 2008 onward), long-term rates fell well below their predicted values. Graph 4 shows that, given the significant rise in both the expected future level of Federal government debt <u>and</u> 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 from 4% in 2008 to over 5% (dashed blue). It actually fell to 3% (red line), below the lower 95% confidence interval (yellow shading).

This large discrepancy reflects the existence of important factors not captured by the empirical model. First of all, continued asset purchases by the Federal Reserve, reinforced by several prominent speeches, could have created the conviction in markets that the central bank will try to keep long-term rates from rising above a certain ceiling seen as incompatible with a rapid return to full employment.

Another reason is that several new, non-monetary factors seem to have increased the demand for government bonds:

- New prudential regulations, mark-to-market accounting rules, actuarial conventions etc induce banks, insurance companies, pension funds and other financial intermediaries to hold a higher proportion of their assets in government bonds (Turner, 2011).
- Increased demand for collateral in financial transactions in wholesale markets. This is coming from the post-crisis decline in unsecured interbank lending and higher swap margin requirements.

The impact of these non-monetary factors may ultimately wane, but the timing of this is highly uncertain. At some point financial institutions will have reconstituted their capital and liquidity buffers. Furthermore, financial institutions that hold a large share of their portfolio in US Treasuries are unlikely to be able to meet the return expectations of their clients (eg to pay satisfactory pensions) and will face increasing pressure to invest in higher-yield assets. Should pre-crisis empirical regularities reassert themselves, the rise in long-term rates could be substantial.

Our estimates can also help to throw some light on: (1) the decline in long-term interest rates in the 2000s and especially the decoupling of long-term rates from short-term rates; and (2) the effects of quantitative easing during the financial crisis. We turn to these issues in turn.

5. The low interest rates of mid-2000s

In February 2005, Alan Greenspan lamented that long-term interest rates had continued to fall even though the Federal funds rate had been raised by 150 basis points to 2.5 percent. In his view there was no obvious explanation, and he famously called this a “conundrum”. In subsequent months, the Federal Reserve continued to raise the Federal funds rate, which reached 5.25 percent in July 2006 and remained at that level until July 2007. But the 10-year long-term rate did not increase as much as it had in previous tightening episodes, being offset by a sizeable decline in the term premium.[30]

Our estimates suggest that an important reason for the decline in the term premium that took place during the early part of the 2000s might have been the shortening of the maturity of public debt in the market. Average maturity reached a peak of over 70 months in the final months of 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 (Graph 3). Based on our estimates, a decline in average maturity of over 12 months is equivalent to a reduction of over 150 basis points in the five-year forward 10-year rate.

Such a reduction matches most of the fall in both variables over the same period. This is shown in Graph 5. The red line plots the cumulative change in the

[30] In January 2002 the 10-year rate was about 5 percent and fell to about 4 percent before the Federal Reserve started tightening and then gradually rose to the 4.8 per cent until mid-2007. Over the same period, the five-year forward 10-year rate and the estimated 10-year premium had declined by around 90 basis points by the time the Federal Reserve started to raise the Federal funds rate and continued to decline thereafter. By the summer of 2007 they were respectively 1.2 and 1.5 percentage points below the level reached in January 2002.

forward rate since January 2002 (2002H1), when average maturity was 70 months; the dashed blue line shows the estimated contributions of average debt maturity and expected future debt.[31] The negative contribution of lower average maturity was, to some small extent, offset by the positive contribution of large expected debt.[32]

It may seem that the reduction in maturity cannot explain the Greenspan conundrum, as most of the shortening of maturity occurred before the Federal Reserve started to tighten the Federal fund rate. To the extent that maturity is an important factor determining the term premium, however, the fact that it remained relatively constant until the middle of 2007 makes it one of the factors that could explain why long-term interest rates failed to rise in the face of rising short-term rates.[33]

One can ask why debt managers did not raise average maturity in response to the narrowing in yield spreads (or to term premia below the historical average) to minimise expected debt servicing costs. There might be at least two complementary reasons. The first is that debt had declined to relatively low levels in the early 2000s after several years of large fiscal surpluses. With low levels of debt, the risk of having to roll over a large amount of short-term debt at high interest rates was small. Blommestein and Turner (2012) found that, as the Federal budget deficit rises, US debt issuance tends to lengthen so that scheduled repayments can be spread over a longer period. The second reason is a strong demand for shorter (and more liquid assets) by foreign investors – especially foreign central banks – and by domestic financial institutions which needed relatively safe short-term assets for their refinancing operations. With the expectation of low debt in the future, debt managers may have simply opted for accommodating the increasing demand for shorter maturities.[34]

31 The model uses half-yearly observations of average maturity sampled at the month in which the CBO releases its projections. Based on these data the semester in which average maturity peaked is 2002H1, which corresponds to January 2002. Looking at the entire monthly series of average maturity, the peak is reached in September 2001 at 73 months.

32 By contrast, the measure of long-term inflation expectations (not shown) was very stable and hence contributed almost nothing to the changes in the dependent variables.

33 Other reasons might include the expectation that the Federal Reserve would quickly reverse the tightening or a change in its targeting procedure. See for example Smith and Taylor (2009) and Thornton (2012).

34 Accommodating demand would mean that debt managers would have responded positively to lower long-term rates or a narrower yield spread. A positive response would amplify the response of the long-term rate or the term premium to a credit boom shock. In that case, the estimated impact of portfolio balance effects in our regressions may be overestimated (ie the OLS coefficient could be biased upward): see Annex 3. We therefore re-ran our regressions ending the sample in 2001, when average maturity peaked, as well as in 1995 before outstanding debt began to decline. In both cases the estimated coefficients on average maturity are very similar to that estimated over the full sample.

6. The effects of Quantitative Easing

Since the start of the crisis several studies have attempted to assess the quantitative importance of central bank purchases of government bonds and related assets. Event studies have generally confirmed that central bank actions have had significant effects on various long-term interest rates on announcement. However, interest rates have increased in some post-announcement periods and it is unclear whether they would have been even higher had the central bank not intervened.

Research has therefore focused on disentangling the effects of central bank actions from other possible determinants of long-term interest rates. Studies using various sample periods, data and empirical strategies differ on the magnitude of these effects. For example, Krishnamurthy and Vissing-Jorgensen (2011) suggest that most purchases are likely to have worked by lowering the expectation of future short-term policy rates. Similarly, Hamilton and Wu (2012) find that the portfolio balance effects of public debt supply are relatively small. Larger effects have been found by Gagnon et al (2010), D'Amico and King (2012) and D'Amico et al (2012). This latter study in particular finds that the purchases of Treasuries by the Federal Reserve contributed to reducing the long-term rate by about 80 basis points in the first two large-scale purchasing programmes. In line with these more recent studies, our estimates also suggest that portfolio rebalance effects of public debt might have been sizeable well before the start of the crisis. For that reason, they cannot be attributed to the signalling effects that central bank balance sheet policies may have had during the crisis.

QE1 was announced in November 2008. Between then and the end of 2012, marketable debt (including Federal Reserve holdings) rose 28.5 percentage points of GDP. The Federal Reserve has absorbed about 7 percentage points of this increase.[35] By buying very long-dated bonds, the Federal Reserve also lowered the average maturity of debt held outside the central bank by about 7 months.[36]

Table 5 shows how much higher the five-year ahead 10-year rate and the 10-year term premium would have been if public debt held outside the central bank had been 7 percentage points higher and average maturity 7 months longer. Specifically, the absorption of 7 percentage points of debt translates into a 12–15 basis points lower forward rate and 0–8 basis points lower term premium. A 7-month lower average maturity translates into an approximately 81–100 basis points lower forward rate and 67–89 basis points lower term premium. Combining the two effects, Fed purchases since November 2008 may have therefore contributed to lowering the five-year forward 10-year rate by approximately 90–115 basis points and the 10-year term premium by approximately 70–95 basis points. These estimates are not too far from those of D'Amico et al (2012) which, using a

[35] December 2012 is the latest available observation.

[36] The average maturity of marketable debt is taken from Quarterly Refunding Report available on the US Treasury website. With the exception of the most recent figures, averages are rounded to nearest integer. Similarly, average maturity of debt held "by the public" (that is, outside the Federal Reserve) in the Table FD5 is also rounded to the nearest integer. Hence, taking the difference between reported figures may overestimate the change in mean maturity attributable to Federal Reserve actions. The average maturity of outstanding marketable debt was 65 months at the end of 2012. It has remained approximately unchanged from this level from the end of September 2012. The average maturity of debt held outside the Federal Reserve was 55 months at the end of September 2012, which is the latest observation available at the time of writing.

different approach and data, reach the conclusion that the first two large-scale purchasing programmes have reduced long-term yields by about 80 basis points (hence without including the effects of the most recent Maturity Extension Program).[37]

7. Monetary policy and central bank holdings of bonds

A possible implication of these results is that, over the very long period when central banks will have (unwanted) government bonds on their balance sheet, central bank sales or purchases of government bonds – or the equivalent decisions of government debt managers – *could* be viewed as a second, quasi-permanent policy instrument. Policies of Quantitative Tightening could complement changes in the policy rate (and forward guidance about the policy rate). Some argue that instrument uncertainty means that using both instruments could increase policy effectiveness.[38] Others argue that too little is known about the quantitative impact of central bank balance sheet policies.

In any event, these two policy instruments are to some degree substitutes. Indeed, the FOMC minutes in April 2011 reveal 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". When and how this normalisation process will be undertaken could have a significant impact on long-term interest rates.

The impact on long-term rates as the central bank shrinks its balance sheet could have serious implications for government financing costs, particularly if large fiscal deficits persist.[39] It could also have consequences for the strength of the financial system. Banks, insurance companies, pension funds and other regulated institutions have built up large bond exposures, partly in response to recent regulatory reforms. They may therefore be at risk of large capital losses when interest rates eventually rise. These risks have undermined the separation between monetary policy and government debt management policy, which had been the prevailing orthodoxy guiding policies from the early 1990s to the financial crisis.[40]

[37] Unfortunately, the figures reported in the official sources are rounded to the first integer making it impossible to compute the exact difference in average maturities. We reckon that taking into account the possible largest rounding errors the difference between average maturities could be as low as 5¼ months. Assuming that the Federal Reserve contributed to alter the mean maturity of privately-held debt by only 5¼ months would give lower estimates of the overall impact: a reduction of 70–90 basis points in the five-year forward 10-year rate and a reduction of 50–75 basis points in the 10-year term premium.

[38] The UK's *Radcliffe Report* in the late 1950s argued along these lines (Turner, 2011). Brainard's Uncertainty Principle in his 1967 article echoed this argument.

[39] There may also be a signalling effect: news that "the central bank is selling" might have a disproportionate effect on market prices because their holdings are so large and because central banks are non-commercial players (Turner, 2013).

[40] The difficulty for economists is that there is no well-established and agreed theory on government debt management as tool of monetary policy. A recent BIS workshop which addressed the

Although this paper has focused on the asset side, there is also a liability side to the central bank's balance sheet. Most would probably regard central bank liabilities, at given interest rates, as reacting passively to decisions about assets. Purchases of Treasuries typically increase bank reserves – government debt is in effect replaced by very short-term bank deposits with the central bank ("money"), which may or may not be interest bearing. As discussed on pp 17-18 above, however, the addition of a variable reflecting Federal Reserve holdings of Treasuries added nothing to the explanation of the 5-year forward 10-year yield.

But central bank liabilities may not necessarily just react endogenously to decisions about assets. 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): if they do, central bank liabilities can hardly be regarded as passively reacting.[41] This paper does not analyse the liability side of the central bank's balance sheet. Therefore, the task of managing what Alan Blinder has called the "veritable mountain" of excess bank reserves (Blinder, 2010) raises issues that go beyond the scope of this paper.

A final note of caution is that what applies to the ability of the Federal Reserve to influence "their" long-term interest rate – which exerts a pervasive global influence – will not necessarily hold for other central banks.

8. Conclusion

The massive expansion of central bank balance sheets since this crisis began will lead to a rethinking about the importance of portfolio balance effects in the working of monetary policy and about the links with government debt management. Central bank purchases of government bonds affect the volume and the maturity of bonds the market is induced to hold, and so might influence the shape of the yield curve. The decisions of government debt managers have very similar effects. The two agents of government do not, however, have the same objective for the yield curve – indeed it is primarily the central bank, not the debt manager, that focuses on the macroeconomic implications of changes in the yield curve.

This paper has shown that, if government debt issuance policies can be treated as exogenous with respect to current and expected interest rate developments, central bank purchases of government bonds have had a large impact on the long-term interest rate. But if government debt managers in fact respond endogenously to interest rates, the estimates of the maturity effect may have an upward bias. More research is needed to learn about the reactions of debt managers to interest rates.

macroeconomics of government debt management revealed significant divergences of view (BIS, 2012).

41 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).

Another important aspect that deserves further research is the extent to which any empirical estimates of the interest rate effects of maturity is a good guide to the future. Indeed, the link between average debt maturity and long-term rates or term premia will depend on the overall policy framework. In particular, it is likely to depend on how fiscal policy is expected to be conducted in the future. Given that public debt has grown to very high levels, fiscal policy may well be conducted differently than during the sample period. Different expected consolidation paths may mean that the same change in debt maturity could have a different impact on long-term rates. In addition, inflation expectations could be destabilised by radical change in debt management policy. All these issues merit further reflection.

References

Andrews, D W K and W Ploberger (1994): "Optimal tests when a nuisance parameter is present only under the alternative", *Econometrica*, Vol 62, pp 1383–414.

Bank for International Settlements (BIS) (2012): *Threat of fiscal dominance?* BIS Papers no 65. May.

Bernanke, B S, V R Reinhart and B P Sack (2004): “Monetary policy alternatives at the zero bound: an empirical assessment”, *Brookings Papers on Economic Activity*, Vol 35(2), pp 1–78.

Blinder, Alan S (2010): “Quantitative easing: entrance and exit strategies”, *Federal Reserve Bank of St Louis Review*. November/December.

Blommestein, H J and P Turner (2012): “Interactions between sovereign debt management and monetary policy under fiscal dominance and financial instability” in BIS (2012), pp 213–237.

Brainard, William (1967): “Uncertainty and the effectiveness of policy”. *Cowles Foundation Paper* 257.

Cecchetti, S G, M S Mohanty and F Zampolli (2010): “The future of public debt: prospects and implications”, *BIS Working Papers* no 300. March. www.bis.org/publ/work300.htm

Chadha, J S (2012): “World real interest rates: a tale of two regimes”, DWS Global Financial Institute, February.

Congressional Budget Office Congress of the United States (2013): “The budget and economic outlook: fiscal years 2013 to 2023. February.

Culbertson, J (1957): “The Term Structure of Interest Rates”, *Quarterly Journal of Economics*, Vol 71, pp 485–517.

D’Amico, S, W English, D Lopéz-Salido and E Nelson (2012): “The Federal Reserve’s large-scale asset purchase programmes: rationale and effects”, *Economic Journal* Vol 122, November.

D’Amico, S and D B King (2012): “Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply”, *Journal of Financial Economics*. Vol 108, pp 425–448.

Doh, T (2010): “The efficacy of large-scale asset purchases at the zero lower bound”, *Federal Reserve Bank of Kansas City Economic Review*, 2nd Quarter.

Eggertsson, G B and M Woodford (2003): “The zero bound on interest rates and optimal monetary policy”, *Brookings Papers on Economic Activity* 1:2003.

Friedman, B M (1978): "Crowding Out or Crowding In? Economic Consequences of Financing Government Deficits", *Brookings Papers on Economic Activity*, Vol 3, pp 593-642.

Gagnon, J, M Raskin, J Remache and B Sack (2010): “Large-scale asset purchases by the Federal Reserve: did they work?”, *Federal Reserve Bank of New York Staff Reports* No 441, March.

Garbade, K D and M Rutherford (2007): “Buybacks in Treasury cash and debt management”, *Federal Reserve Bank of New York Staff Report* no 304, October.

Goodhart, Charles (2013): "Financial repression will play part in unwinding a swollen balance sheet". http://fw.ifslearning.ac.uk

Greenwood, R, S Hanson and J Stein (2010): "A comparative-advantage approach to government debt maturity", Working Paper, Harvard University.

Greenwood, R and D Vayanos (2010a): "Price pressure in the government bond market", *American Economic Review*, Vol 100, Issue 2, pp 585–590.

Greenwood, R and D Vayanos (2010b): "Bond supply and excess bond returns", Working Paper, London School of Economics.

Hamilton, J D and J C Wu (2012): "The effectiveness of alternative monetary policy tools in a zero lower bound environment", *Journal of Money, Credit, and Banking*, Vol 44(S1), pp 3–46.

Hansen, B E (1997): "Approximate asymptotic p values for structural-change tests", *Journal of Business & Economic Statistics*, Vol 15(1), pp 60–67.

Hansen, B E (2001): "The new econometrics of structural change: dating breaks in US labor productivity", *Journal of Economic Perspectives*, Vol 15(4), pp 117–128.

Hanson, S G and J C Stein (2012): "Monetary policy and long-term real rates", Finance and Economics Discussion Series no 2012-46, Federal Reserve Board.

Hoogduin, L, B Öztürk and P Wierts (2011): "Public debt managers' behaviour: Interactions with macro policies", Revue Économique Vol 6, pp 1105-1122

Hördahl, P and O Tristani (2010): "Inflation risk premia in the US and the euro area," BIS Working Paper no 325, November.

Hrung, W B and J S Seligman (2011): "Responses to the financial crisis, treasury debt, and the impact on short-term money market rates", Federal Reserve Bank of New York Staff Reports no 481.

Kejriwal, M and P Perron (2008): "The limit distribution of the estimates in cointegrated regression models with multiple structural changes", *Journal of Econometrics*, Vol 146, pp 59–73.

Krishnamurthy, A and A Vissing-Jorgensen (2010): "The Aggregate Demand for Treasury Debt", working paper, Northwestern University.

Krishnamurthy, A and A Vissing-Jorgensen (2011): "The effects of quantitative easing on interest rates: channels and implications for policy", *Brooking Papers on Economic Activity*, Fall.

Kuttner, N K (2006): "Can central banks target bond prices?", NBER Working Paper no 12454.

Laubach, T (2009): "New evidence on interest rate effects of budget deficits and debt", *Journal of the European Economic Association* 7(4), pp 858–885.

Lettau, M, and S Ludvigson (2001): "Consumption, aggregate wealth, and expected stock returns." *Journal of Finance*, Vol 56, pp 815–849.

Meaning J and F Zhu (2011): "The impact of recent central bank asset purchase programmes", *BIS Quarterly Review*, December.

Meaning J and F Zhu (2012): "The impact of Federal Reserve asset purchase programmes: another twist", *BIS Quarterly Review*, March.

Missale, Alessandro (2012): "Sovereign debt management and fiscal vulnerabilities" in BIS (2012), pp 157–176.

Modigliani, F and R Sutch (1966): “Innovations in interest rate policy”, *American Economic Review*, Vol 56, No 1/2, pp 178–197.

Modigliani, F and R Sutch (1967): “Debt management and the term structure of interest rates: An empirical analysis of recent experience”, *Journal of Political Economy*, Vol 75, No 4, Part 2, pp 569–589.

OECD (2013): *OECD Sovereign Borrowing Outlook 2013*, Paris.

Orphanides, A (2003): “Historical monetary policy analysis and the Taylor rule”, *Journal of Monetary Economics*, Vol 50, pp 983–1022.

Pozsar, Z (2011): “Institutional cash pools and the Triffin dilemma of the US banking system”, *IMF Working Paper* No 11/190.

Siegel, Jeremy (2013): “Time for Fed to bring its third policy tool out of hibernation”. *Financial Times*. 28 March.

Smith, J M and J B Taylor (2009): "The term structure of policy rules," *Journal of Monetary Economics*, Vol 56(7), pp 907–917.

Swanson, E (2011): “Let’s twist again: A high-frequency event-study analysis of Operation Twist and its implications for QE2”, *Brookings Papers on Economic Activity*, Spring, pp 151–187.

Thornton, D L (2012): “Greenspan’s conundrum and the Fed’s ability to affect long-term yields”, *Federal Reserve Bank of St. Louis Working Paper* no 2012-036A, September.

Tobin, J (1961): "Money, Capital and Other Stores of Value", American Economic Review, Vol 51 (2), pp 26-37.

Tobin, J (1963), “An essay on principles of debt management”, *Cowles Foundation Paper* 195; Ch 21 in J Tobin (1987), *Essays in Economics*. Volume 1: Macroeconomics, MIT Press. pp 378–455.

Tobin, J (1969): "A General Equilibrium Approach to Monetary Theory", Journal of *Money, Credit and Banking*, Vol 1 (1), pp15-29.

Turner, P (2011): “Is the long-term interest rate a policy victim, a policy variable or a policy lodestar?”. *BIS Working Paper* no 367. December.

Turner, P (2013): “The benign neglect of the long-term interest rate”. *BIS Working Paper* no 403. February.

Vayanos, D and J L Vila (2009): “A preferred-habitat model of the term structure of interest rates”, *NBER Working Paper* No 15487.

Warnock, F E and V C Warnock (2009): “International capital flows and US interest rates”, *Journal of International Money and Finance* 28, pp 903-919.

Zampolli, F (2012): “Sovereign debt management as an instrument of monetary policy: an overview”, in BIS (2012), pp 97–118.

Annex 1: Tests of unit roots and cointegration

Our unit root tests (see Annex Table A1) support the assumption that the five-year forward 10-year rate, the constant maturity 10-year rate and inflation expectation exhibit a unit root. The three-month Treasury bill also appears to have a unit root although the evidence is less strong. As to the fiscal variables, the statistical evidence for the projected future debt-to-GDP ratio and the projected future deficit is also mixed with most tests indicating stationarity. The Augmented Dickey-Fuller tests cannot reject the null of a unit root but p values are generally lower than the interest rate variables. At the same time the Phillips-Perron test strongly rejects a unit root. The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test cannot reject the null of stationarity at the 10% significance level for projected debt, while it cannot reject the null for projected deficit at the 5% level.

Up to here, our results are in line with those of Laubach (2009), who also stress the very low power of unit root tests in small samples. One variable that is not in the original dataset is the average maturity of public debt. For this variable, one test indicates the presence of a unit root, while the others suggest stationarity.

Clearly, the sample is too short to rely solely on tests of unit roots, which have very low power. Plots of the series as well as a-priori knowledge suggest that the assumptions on which Laubach's basic regression (2009) is based are plausible. There is also no strong reason a priori to believe that the average maturity of public debt is not a stationary variable.

We also have tested for the existence of cointegration among the basic variables that form our basic regressions. Annex Table A2 in the Annex shows no clear evidence of cointegration between the five-year forward 10-year interest rate and the measure of inflation expectation. While this may be due again to the small power of the tests in small samples, Johansen's test of cointegration cannot reject the hypothesis of cointegration (Annex Table A3). As shown by Annex Table A2, adding fiscal variables to the basic cointegration relationship does not overturn but strengthen the conclusion that the two series are cointegrated.

Annex 2: Structural break analysis

This appendix describes the procedure used to identify structural breaks in our sample. In searching for structural breaks we assume that all coefficients except that of inflation expectations in our baseline specification could be subject to a structural break at an unknown date. We rule out the coefficient on long-term inflation expectations, which is found to be cointegrated with the nominal forward rate (Annex 1).

In the presence of a structural break our baseline regression can be written in matrix form as follows:

(A2.1) $$f_t = \theta_0' x_t + \theta_1' x_t 1(t \leq t_b) + \theta_2' x_t 1(t > t_b) + \varepsilon_t$$

where the vector of regression coefficients $\theta_1$and θ_2 may include (as in our case) the intercept. The break date t_b is unknown and needs to be estimated. The vector θ_0 refers to the variables that are assumed to be fixed across regimes (in our case inflation expectations).

It is convenient to rewrite (A2.1) as:

(A2.1) $$f_t = \theta_1' x_t + \delta' x_t 1(t > t_b) + \varepsilon_t$$

We can test for the existence of a structural break in the coefficients using a Chow test for the null hypothesis that $\delta = \theta_2 - \theta_1 = 0$. If the break date is known, the distribution of this test follows a standard distribution. However, if the break date is unknown, the test distribution is non-standard because it depends on a parameter which is not identified under the null hypothesis. Andrews and Ploberger (1994) provides critical values for this test and Hansen (1997) has developed approximate p-values.

The other consequence of not knowing the break date is that we have to assume that each date in the sample (at least within a given interval) could be a possible break date. Hence, we compute a sequence of F statistics associated with different candidate break dates within the interval $t_0 + \pi_0 \leq t_b \leq t_1 - \pi_0$, where the dates t_0 and t_1 indicate the start and end dates of the sample, respectively, and π_0 is a trimming parameter. The latter is chosen to ensure that there is a minimum number of observations in each regime and that the regression is well-behaved.

Our sample is 1976H1–2011H2 for a total of 63 observations.[42] We trim seven observations (or around 11% of available observations) both at the beginning and the end of the sample. We find that these are the minimum number of observations that could be left in both regimes without giving rise to collinearity.

The top panel in Graph A1 plots the F statistic value as a function of the candidate break date. The F statistic (computed using Newey-West standard errors) has a clear peak of 48.8886 at 1985H2. Using Hansen's approximate p-values the statistic is significant at 1% level.[43] In the presence of homoscedastic errors the peak

[42] If all observations were semi-annual the sample should have a total of 72 observations. However, note that the sample before 1985 has a mix of annual and semi-annual observations.

[43] The aveF statistic is 4.1563, which has an approximate p-value of 0.75 (with a trim parameter of 0.15). The expF statistic is 20.5525, which is significant at 1% level.

in the F test would correspond to the trough in the residual variance. Yet the residual variance has a minimum at 1986H1. Hence we identify a break at 1986H1.

To check whether there are other breaks in the regression, we re-compute the sequence of F tests over the period 1986H1–2011H2 ensuring that there are sufficient number of observations in both regimes to avoid collinearity. We find that the F statistic tends to peak at the end of the sample and the residual variance has a global minimum in 2008H2.

Based on the structural break analysis we estimate our baseline regression over the sample 1976H1–2088H1 allowing for a break in all coefficients (bar that of inflation expectations) in 1986H1. The estimates are reported in Annex Table A4. Kejriwal and Perron (2008) show that in a cointegrated model with structural changes, which allows both stationary and integrated regressors, the limiting distribution of the estimates of the regression coefficients is the same as that obtained when the break dates are known. We therefore use a standard distribution to test the restriction shown at the bottom of Annex Table A4.

Annex 3: A stylised model of interest rate effects of debt maturity and debt managers' choices

In this annex we set up a stylised model to gain some intuition on the role that debt managers' decision may play in influencing term premia and the possible estimation biases that may arise from debt managers' choices in regressing a measure of the long-term interest rate or the term premium on average maturity.

The model consists of two equations. The first one states that the long-term premium is a function of maturity *m*, debt *d* and a shock *u*:

(A3.1) $$\tau_t = \alpha m_t + \gamma d_t + u_t$$

For simplicity, we assume that τ is a real interest rate or real term premium. All variables should be interpreted as deviations from their long-run mean. Equation (A3.1) reflects the existence of portfolio balance effects through *m* and crowding-out effects through *d*. Other unspecified effects are captured by the shock *u*.

The second equation describes the behaviour of debt managers in response to changes in the macroeconomic environment:

(A3.2) $$m_t = \beta E_t \tau_{t+s} + \delta E_t d_{t+s} + \varepsilon_t$$

Maturity depends on the expectation of the future term premium and future debt s periods ahead and a shock ϵ. Debt is assumed to be exogenous.

We further assume that the shocks u and ϵ and debt follow autoregressive processes of order one with the autoregressive coefficient given by ρ_u, ρ_ε and ρ_d respectively.

We make the further plausible assumption that debt managers understate the maturity effects of debt on interest rates. For simplicity, we assume that debt managers completely ignore maturity effects – that is, they believe that $\alpha = 0$ in (A3.1). Hence, from (A3.1) the expectation of the term premium s periods ahead is:

(A3.3) $$E_t \tau_{t+s}^{(\alpha=0)} = \gamma \rho_d^s d_t + \rho_u^s u_t$$

Using this we can solve the model expressing both maturity and the term premium as functions of debt and the shocks *u* and ϵ:

(A3.4) $$m_t = (\beta\gamma + \delta)\rho_d^s d_t + \beta \rho_u^s u_t + \varepsilon_t$$

(A3.5) $$\tau_t = (\alpha(\beta\gamma + \delta)\rho_d^s + \gamma) d_t + (\alpha\beta\rho_u^s + 1) u_t + \alpha\varepsilon_t$$

We can use (A3.4)-(A3.5) to compute the effects on the term premium of a shock *u* and fiscal changes *d*:

(A3.6) $$\frac{\partial \tau_t}{\partial u_t} = 1 + \alpha\beta\rho_u^s$$

(A3.7) $$\frac{\partial \tau_t}{\partial d_t} = \gamma(1 + \alpha\beta) + \alpha\delta\rho_d^s$$

Expression (A3.6) shows that a shock to the term premium *u* is amplified or dampened depending on the sign of the debt managers' response β to changes in the expected future term premium. If debt managers shorten maturity when the future term premium is expected to be high and vice versa (β<0), then the impact of the initial shock is dampened. By contrast, if debt managers lengthen maturity when the term premium is high (β>0), then they act to amplify the initial shock to debt. The magnitude of the amplification depends positively on the size of the portfolio balance effects and the persistence of the shock.

Why should debt managers raise maturity when the term premium is expected to be higher in the future? By issuing more long term securities debt managers will lock in the current lower interest rates. Higher future interest rates may also go hand in hand with higher rollover risk if current average maturity is too short. Cost minimisation and risk considerations should lead debt managers to raise the maturity today if they expect term premia to be higher and market conditions more difficult in the future.

Why should debt managers reduce the maturity when they expect long-term term premia to be lower in the future? Shortening maturities today would reduce cost immediately as the yield spread is normally positive. At the same time, rollover risks are smaller if debt managers hold the view that future term premia will be lower.

The above considerations regarding the potential amplifying behavior of debt managers run counter with comments often made in several recent studies – namely that estimates of maturity effects should be biased downward, thus making estimated coefficients a conservative estimates of true portfolio balance effects.

Expression (A3.7) shows that the effect of a fiscal shock *d* on the term premium depends on three factors: the first is the direct effect of debt as measured by γ; the second is the indirect effect due to response of debt managers to the change in the term premium; the third is the indirect effect of debt managers responding to changes in the size of debt. Both indirect effects work through maturity and hence they are stronger the larger is α.

One can also use (A3.4)-(A3.5) to compute the OLS coefficients of a regression of the term premium on maturity. Let us indicate the estimated coefficient with $\hat{\alpha}$. Then the bias in the OLS estimate is:

(A3.8)

$$\hat{\alpha} - \alpha = \frac{\beta \rho_u^s \sigma_u^2 + \gamma(\delta + \beta\gamma)\rho_d^s \sigma_d^2}{(\beta\gamma + \delta)^2 \rho_d^{2s} \sigma_d^2 + \beta^2 \rho_u^{2s} \sigma_u^2 + \sigma_\varepsilon^2}$$

The bias in the coefficient is generally ambiguous as it depends on two terms. However, if β>0 the estimated coefficient is clearly biased upward. The bias is larger the more prevalent and more persistent are shocks to the term premium and fiscal shocks. On the other hand, the bias would be smaller the more prevalent are exogenous movements in maturity.

The bias in the OLS estimate of γ is:

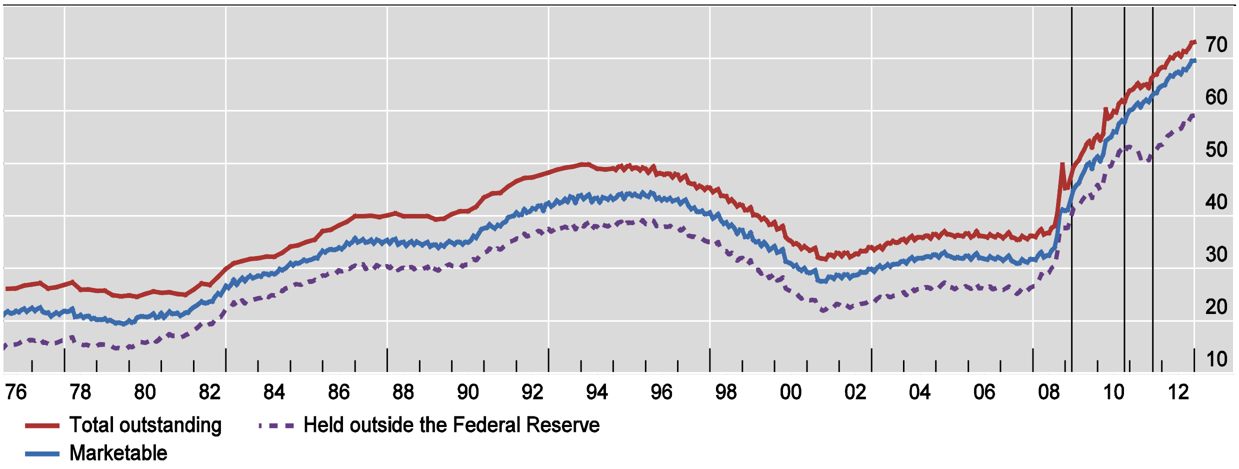
(A3.9) $$\hat{\gamma} - \gamma = \alpha(\delta + \beta\gamma)\rho_d^s$$

The bias on the effect of debt on long-term interest rate depends on the persistence of fiscal shocks. An increase in debt has two effects on interest rates, which will be captured by the OLS estimate. The first is to raise expected future term premia by ρ_d^s . As debt managers anticipate an increase in the long-term rate or the term premium, they will issue more longer-dated securities, thus raising average maturity by $\beta\gamma\rho_d^s$. In turn, the increase in average maturity will raise the term premium by $\alpha\beta\gamma\rho_d^s$. The second effect of a fiscal shock is to cause debt managers to raise maturity by $\delta\rho_d^s$, which will raise the term premium by $\alpha\delta\rho_d^s$.

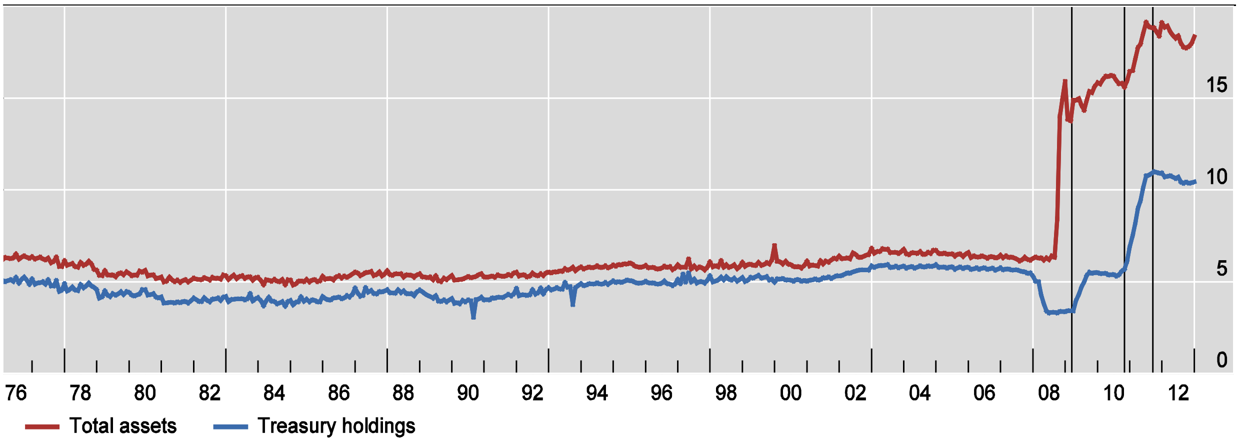
Graphs and tables

Treasury debt and Federal Reserve holdings (% of GDP)

Holders of US public debt Graph 1



Balance sheet of the Federal Reserve

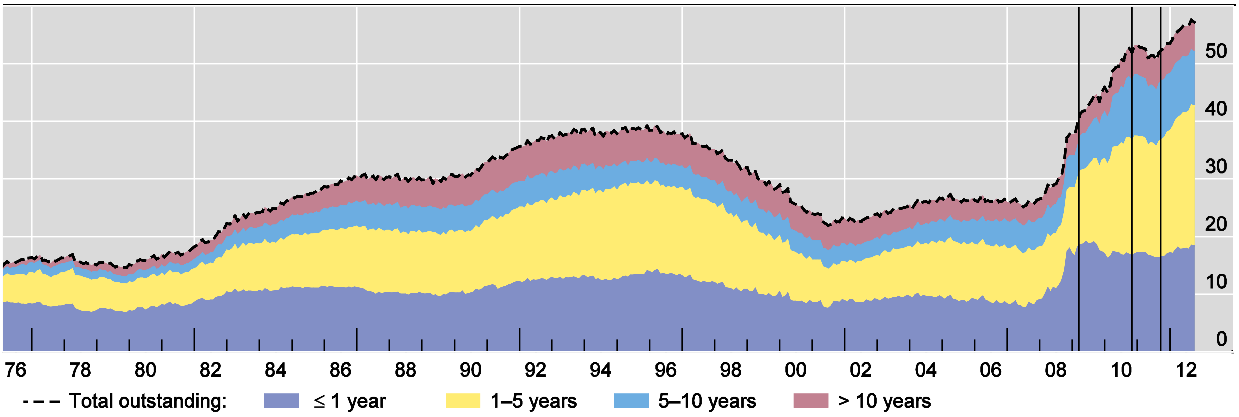


The vertical lines correspond to March 2009 (LSAP1), November 2010 (LSAP2) and September 2011 (MEP).

Sources: Datastream; national data; BIS calculations.

Marketable debt held outside the Federal Reserve: maturity breakdown

In per cent of GDP — Graph 2

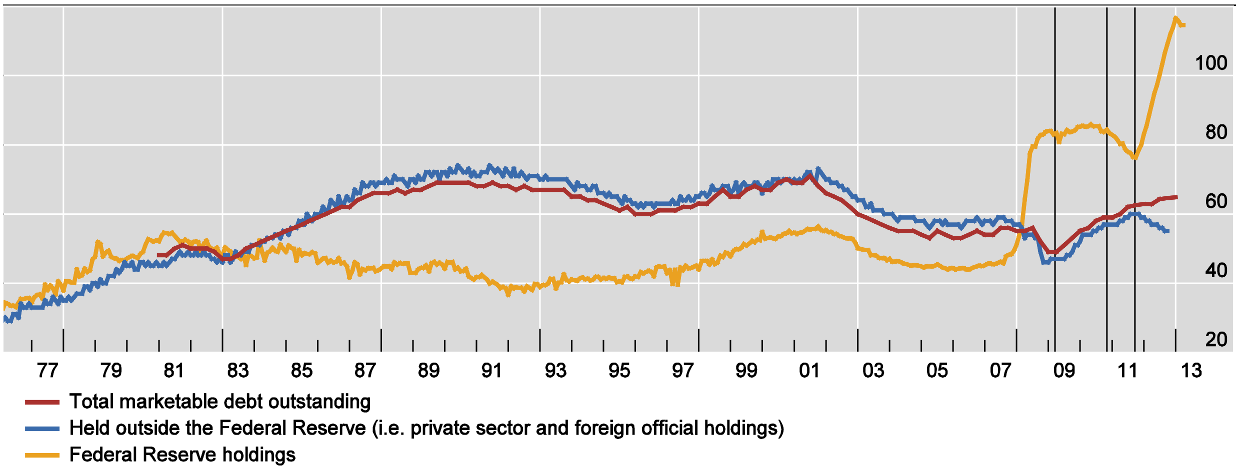


The vertical lines correspond to March 2009 (LSAP1), November 2010 (LSAP2) and September 2011 (MEP).

Sources: Datastream; national data

Average maturity of outstanding Treasury debt

In months | Graph 3



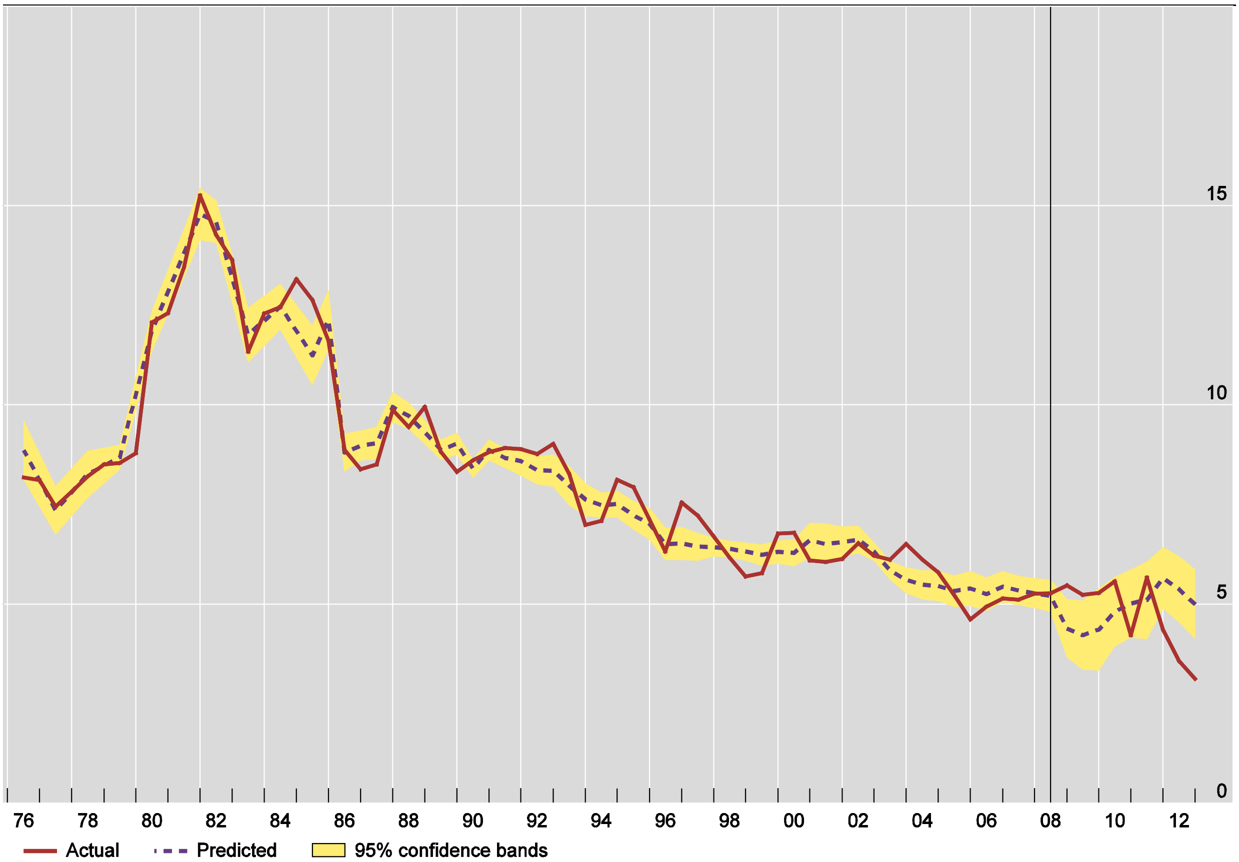
The vertical lines correspond to March 2009 (LSAP1), November 2010 (LSAP2) and September 2011 (MEP).

Sources: US Treasury; BIS calculations.

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

In per cent

Graph 4

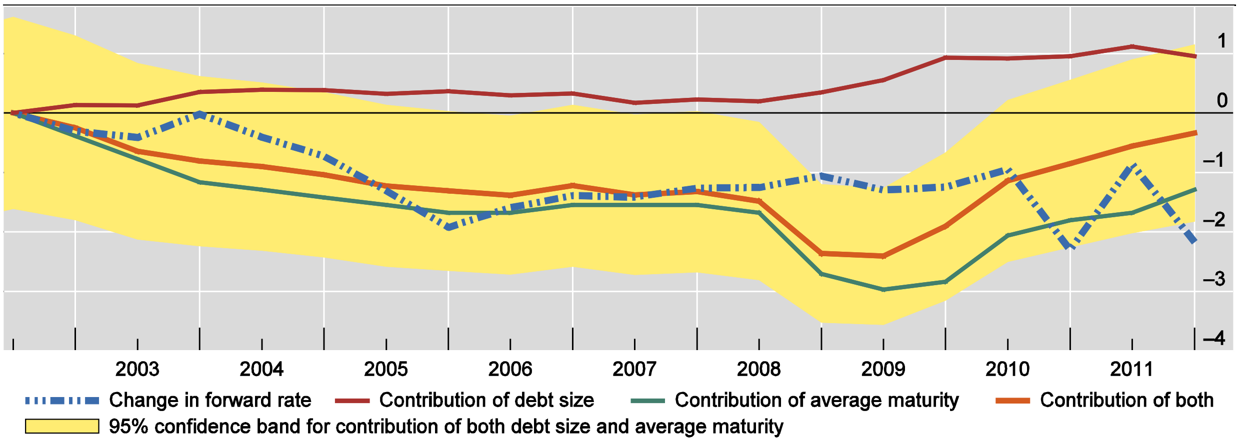


[1] Predicted values are from a regression of the 5-year forward 10-year rate on average maturity of federal debt held outside the Federal Reserve and other regressors. Value to the right of the vertical line are out-of-sample predictions.

Contributions of public debt and its maturity to 5-year forward 10-year rate [1]

In percentage points

Graph 5



[1] .Predicted values from a regression of the 5-year forward 10-year rate. Cumulative change in the forward rate since January 2002 (2002H1), when average maturity was 70 months.

Five-year forward 10-year rate

Table 1

	1976H1-2008H1					1986H1-2008H1	
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).

Five-year forward 10-year rate, business cycle, Fed holdings and official inflows Table 2

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Inflation expectation	0.999***	0.942***	1.007***	1.117***	0.778***	0.972***	1.139***
	(0.068)	(0.094)	(0.074)	(0.128)	(0.279)	(0.068)	(0.190)
Five-year ahead debt	0.021***	0.023***	0.028***	0.024***	0.019	0.019***	0.036***
	(0.005)	(0.005)	(0.006)	(0.005)	(0.012)	(0.005)	(0.012)
Average maturity	0.129***	0.126***	0.124***	0.143***		0.138***	
	(0.012)	(0.012)	(0.014)	(0.019)		(0.017)	
Dividend yield (t<86H2)	-0.802***	-0.834***	-0.961***	-0.828***	-0.312	-1.192***	-1.465***
	(0.290)	(0.275)	(0.239)	(0.276)	(0.621)	(0.187)	(0.344)
Tbill volatility (t<86H2)	2.973***	2.869***	3.125***	2.914***	3.174***	3.113***	3.367***
	(0.257)	(0.329)	(0.231)	(0.263)	(0.622)	(0.284)	(0.840)
Three-month bill rate		0.036					
		(0.055)					
Real-time output gap			0.049				
			(0.035)				
Fed holdings of Treasuries				0.304	-0.968**		
				(0.289)	(0.391)		
Official inflows into Treasuries						0.327	-0.522*
						(0.198)	(0.269)
Observations	56	56	53	56	56	53	53
Adj R2	0.955	0.955	0.952	0.956	0.892	0.960	0.901

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 variable 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 3
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.

Recent values for key variables

Table 4

	f	π	d%y	m
2006	5.1	2.2	37.8	58
2007	5.3	2.1	33.1	58
2008	5.5	2.1	38.7	49
2009	5.30	2.1	66.0	48
2010	4.2	2.0	67.3	56
2011 H1	5.7	1.9	75.0	57
2011 H2	4.4	2.1	67.2	60
2012 H1	3.6	2.1	68.5	58
2012 H2	3.1	2.0	68.0	55
2013 latest	3.0	1.9	73.1	

Notes: f = five-year forward 10-year rate; π = long-term inflation expectation; d%y = 5-year ahead projected debt to GDP ratio; m = average maturity of Federal debt held outside the Federal Reserve.

Potential effects of central bank purchases of Treasuries since November 2008

Table 5

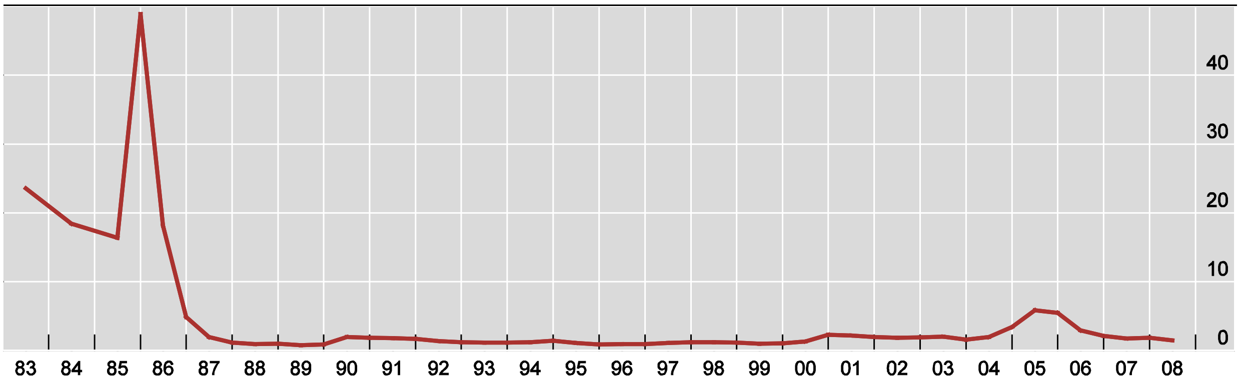
		5y forward 10y rate				10y term premium			
	Change	Marginal effect (range)		Total effect (range)		Marginal effect (range)		Total effect (range)	
Debt held outside the central bank (% of GDP)	7	*1.7*	*2.1*	12	15	*0*	*1.2*	0	8
Average maturity (months)	7	*11.6*	*14.3*	81	100	*9.6*	*12.7*	67	89
Total effect (bps)				93	115			67	97

Notes: Change in the first column refers to changes in debt held outside the Federal Reserve which could be attributed to central bank interventions since November 2008. The range is selected by taking the min and max estimated coefficients in Table 1-2 (forward rate) and Table 3 (term premium).

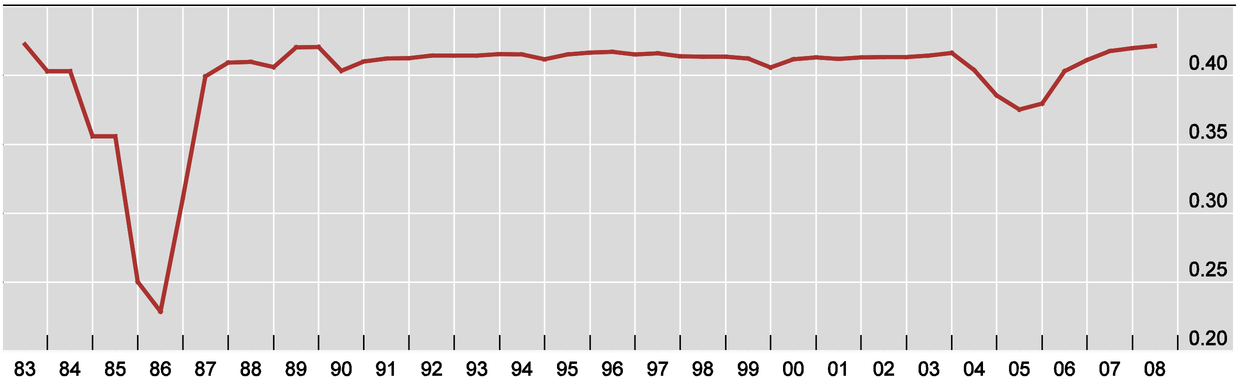
Structural break tests

Graph A1

F-statistic



Residual variance



Source: Authors' calculations.

Unit root tests

Annex Table A1

Variables	Test	Lag	Statistic	Approx. p	1% CV	5% CV	10% CV	T
5-year forward 10-year rate	ADF	1	-1.33	0.61	-3.56	-2.92	-2.60	62
	PP	3	-1.21	0.67	-3.56	-2.92	-2.60	63
	KPSS	3	1.12	--	0.74	0.46	0.35	63
Const. maturity 10-year yield	ADF	0	-1.38	0.59	-3.56	-2.92	-2.60	63
	PP	3	-1.35	0.61	-3.56	-2.92	-2.60	63
	KPSS	3	1.18	--	0.74	0.46	0.35	63
Inflation expectation	ADF	4	-0.98	0.76	-3.57	-2.92	-2.60	59
	PP	3	-0.61	0.87	-3.56	-2.92	-2.60	63
	KPSS	3	1.48	--	0.74	0.46	0.35	63
3-month treasury bill rate	ADF	2	-2.00	0.29	-3.57	-2.92	-2.60	61
	PP	3	-1.96	0.31	-3.562	-2.92	-2.595	63
	KPSS	3	0.95	--	0.74	0.46	0.35	63
Projected debt	ADF	2	-1.95	0.31	-3.63	-2.95	-2.61	43
	PP	3	-3.06	0.03	-3.61	-2.94	-2.61	46
	KPSS	3	0.45	--	0.74	0.46	0.35	46
Projected deficit	ADF	2	-1.75	0.40	-3.63	-2.95	-2.61	43
	PP	3	-4.00	0.00	-3.61	-2.94	-2.61	46
	KPSS	3	0.48	--	0.74	0.46	0.35	46
Average maturity	ADF	4	-3.13	0.02	-3.64	-2.96	-2.61	41
	PP	3	-1.87	0.35	-3.61	-2.94	-2.61	46
	KPSS	3	0.43	--	0.74	0.46	0.35	46

Notes: ADF is the Augmented Dickey Fuller test for the null of a unit root against the alternative of stationarity (no trend); PP is the Perron Philips test for the null of a unit root (no trend); and KPSS is the Kwiatkowski-Phillips-Schmidt-Shin test for the null of level stationarity. Approx. p-value is the MacKinnon's approximate p value of the computed statistic. Observations are halfyearly and start in 1976. However, because there are gaps for some series in the early part of the sample, the test sample will start at a later date. T shows the number of observations available.

Cointegration tests

Annex Table A2

Variables	Test	Lag	Stat	1% CV	5% CV	10% CV	T	N
	ADF	1	-3.23	-4.08	-3.44	-3.11	62	2
5-yr forward 10-yr rate,	PP	3	-3.07	-4.08	-3.43	-3.11	63	2
inflation exp	KPSS	3	0.20	0.74	0.46	0.35	63	-
5-yr forward 10-yr rate,	ADF	1	-3.88	-4.16	-3.48	-3.14	44	2
inflation exp,	PP	3	-4.46	-4.15	-3.47	-3.14	46	2
5-yr ahead debt	KPSS	3	0.11	0.74	0.46	0.35	46	-
5-yr forward 10-yr rate,	ADF	1	-3.58	-4.16	-3.48	-3.14	44	2
inflation exp,	PP	3	-4.70	-4.15	-3.47	-3.14	46	2
5-yr ahead deficit	KPSS	3	0.14	0.74	0.46	0.35	46	-
5-yr forward 10-yr rate,	ADF	1	-4.50	-4.16	-3.48	-3.14	44	2
inflation exp, 5-yr ahead	PP	3	-4.69	-4.15	-3.47	-3.14	46	2
debt, avg maturity	KPSS	3	0.17	0.74	0.46	0.35	46	-
5-yr forward 10-yr rate,	ADF	1	-4.24	-4.16	-3.48	-3.14	44	2
inflation exp, 5-yr ahead	PP	3	-4.85	-4.15	-3.47	-3.14	46	2
deficit, average maturity	KPSS	3	0.18	0.74	0.46	0.35	46	
5-yr forward 10-yr rate,	ADF	1	-4.19	-4.16	-3.48	-3.14	44	2
inflation exp, trend	PP	3	-4.68	-4.15	-3.47	-3.14	46	2
growth, dividend yield	KPSS	3	0.08	0.74	0.46	0.35	46	-

Notes: This table reports residual-based tests of cointegration. For the Augmented Dickey Fuller (ADF) and the Phillip Perron (PP) tests, the critical values tabulated from the response surfaces tabulated by MacKinnon (2010) for the no trend case. T indicates the number of observations used to compute the test statistic. N indicates the number of I(1) variables in the estimated cointegrating relationship. The null hypothesis in the ADF and PP tests is the presence of a unit root in the regression. The Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test tests for the null of level stationarity in the residuals. Observations are halfyearly and start in 1976. However, because there are gaps for some variables in the early part of the sample, the estimation sample starts at a later date.

Johansen's tests of cointegration – 5-year forward 10-year rate and inflation expectation

Annex Table A3

No of CE(s)	Eigenvalue	Trace stat	5% CV
None	0.292	21.97	15.49
At most 1	0.020	1.21	3.84

No of CE(s)	Eigenvalue	Max-Eigenvalue stat	5% CV
None	0.292	20.75	14.26
At most 1	0.020	1.21	3.84

Notes: Estimated VAR for differences has 3 lags. Number of observations is T=60.

5-year 10-year interest rate, structural break model

Annex Table A4

Variables	(1)	(2)
Inflation expectation	0.962***	1.048***
	(0.073)	(0.070)
Five-year ahead debt (t<86H2)	-0.008	
	(0.016)	
Five-year ahead debt (debt5) (t>=86H2)	0.017**	
	(0.008)	
Average maturity (t<86H2)	0.150***	
	(0.031)	
Average maturity (t>=86H2)	0.115***	
	(0.017)	
Trend growth (t<86H2)	-1.201***	-0.862***
	(0.224)	(0.289)
Trend growth (t>=86H2)	-0.144	
	(0.260)	
Dividend yield (t<86H2)	-0.849***	-0.934***
	(0.146)	(0.247)
Dividend yield (t>=86H2)	0.101	
	(0.090)	
Tbill volatility (t<86H2)	2.873***	2.997***
	(0.204)	(0.250)
Tbill volatility (t>=86H2)	0.529	
	(0.929)	
Intercept break (t>=86H2)	-10.723***	-10.524***
	(2.074)	(1.408)
Five-year ahead debt		0.017***
		(0.006)
Average maturity		0.121***
		(0.013)
Intercept	6.754***	5.992***
	(1.406)	(1.624)
Observations	56	56
Adj R2	0.956	0.958

Test:
1) debt5_l - debt5_r = 0; 2) avgmatfd5_l - avgmatfd5_r = 0; 3) gr5_r = 0
4) dwr_r = 0; 5) volm3_12m_r = 0
F(5, 43) = 1.19
Prob > F = 0.3296

Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.