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Net debt supply shocks in the euro area and the implications for QE

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Abstract

This paper examines how shocks to the net supply of government bonds affect the euro area term structure of interest rates and the wider macroeconomy. To measure net debt supply we construct a new free-float measure, which adjusts total government debt of the four largest euro area economies for foreign official holdings and the maturity of the outstanding stock of debt. Using a small macro-finance BVAR model, we estimate that the ECB's government bond purchases, as announced on 22 January 2015, reduced euro area 10-year bond yields, on average, by around 30bps in 2015 through the so-called duration channel. The impact on the output gap and inflation in 2016 is of the order of 0.2ppt and 0.3ppt respectively. Our estimates are likely to underestimate the overall impact of the ECB's purchases on interest rates and inflation, as they exclude effects on credit risk and monetary policy expectations that may have compressed interest rates even further.

JEL Codes: C5, E4, E5, G1.

Key Words: Term structure, Quantitative Easing, government debt, ECB, macroeconomy.

Non-technical summary

With the advent of the global financial crisis, some central banks began to make large-scale asset purchases with the aim of reducing the broad costs of finance facing firms and households and boosting asset prices, in order to stimulate aggregate demand and achieve their price stability objectives.

In January 2015, the ECB also announced an expanded Asset Purchase Programme (APP), with purchases of government bonds comprising the largest component. Under the APP, it was initially decided that the Eurosystem would buy €1.1 trillion of public and private assets at a pace of €60bn a month from March 2015 until end-September 2016, or until the Governing Council judged that there had been a sustained adjustment in the path of inflation consistent with achieving inflation below, but close to, 2% in the medium term. In December 2015, the intended horizon of the APP was lengthened to at least March 2017 and in March 2016 the Governing Council decided to expand its size to €80bn a month.

In this paper, we examine the likely effects of ECB government bond purchases on euro area interest rates and show how these effects are transmitted to the wider economy. Our analysis is based on empirical evidence on how changes in the amount of government bonds available to private investors in the four largest euro area economies (Germany, France, Italy and Spain) have affected debt-weighted government bond yields historically and how these changes have spilled over into economic activity and consumer prices.

Because the ECB in the past never purchased government bonds as part of its regular monetary policy operations, we construct a new measure of the "free-float" of government bonds in the euro area, which weights together the amount of outstanding debt by its maturity structure and subtracts bonds that are held by overseas official institutions like central banks and sovereign wealth funds. These institutions are a major player in euro area bond markets: they are the single largest investor group in some key segments of the euro area government bond market and are currently estimated to hold around 15% of the total outstanding stock of euro area debt. The reason that these bonds are excluded is that purchases by foreign central banks or by the ECB can be thought of as having similar effects on euro area interest rates.

Our analysis finds that by reducing the amount of bonds available to private investors, purchases of bonds by official institutions put downward pressure on euro area government bond yields. Lower interest rates, in turn, stimulate economic activity and put upward pressure on consumer prices. We use these past regularities between the effective supply of bonds and yields to simulate the impact of the ECB's public sector purchase programme (PSPP) on both the euro area yield curve and the macroeconomy. Taking into account the size of the programme and the envisaged split of purchases between short- and long-term bonds, we estimate that the PSPP, as announced in January 2015, may have reduced euro area long-term yields, on average, by as much as 30bps in 2015 and raised the output gap and inflation by some 0.2ppt and 0.3ppt respectively in 2016. Importantly, these estimates are likely to underestimate the overall impact of the ECB's purchases on interest rates as they exclude effects on credit risk and monetary policy expectations that are likely to have compressed interest rates even further. Moreover, our analysis does not take into account the extension of the intended horizon of the APP to March 2017, announced in December 2015, or the expansion in the monthly volume of APP purchases, announced in March 2016.

1. Introduction

In this paper, we provide empirical evidence on the importance of changes in the debt structure, i.e. the net supply of bonds and related duration in the hands of private price-sensitive investors, in shaping the euro area synthetic debt-weighted term structure based on the four largest euro area Member States (henceforth euro area). We then use these results to gauge the impact of the ECB's Public Sector Purchase Programme (PSPP) on the euro area yield curve and the macroeconomy.

When the PSPP was announced on 22 January 2015, euro area yields fell significantly, extending gains in bond prices already recorded in anticipation of the programme. Yields fell further when the ECB began its purchases in March 2015. The downward impact on yields has been partly explained by policy-makers in terms of a "creation of scarcity" and by a reduction in the "overall duration risk borne by the market" (Cœuré, 2015). The first channel refers to the fact that the APP creates a scarcity in some bonds that are considered special by private investors, leading investors to push up prices and lower yields if these securities cannot easily be replaced with other securities featuring similar characteristics. Indeed, the relative safety and liquidity of government bonds – even if not uniform in their characteristics across euro area Member States – and their wide use in repo markets as collateral, gives them a special value to certain investors – so-called preferred habitat investors – which goes beyond simple pecuniary motives, similar to the role of Treasuries in the United States (see e.g. Krishnamurthy and Vissing-Jorgensen, 2012). The second and broader channel reflects the fact that by removing duration risk from the market, the APP is expected to initiate a general repricing of euro area debt across the yield curve, leading to lower premia and yields across all euro area bonds.

The international evidence typically shows that financial prices have indeed responded significantly to central bank asset purchase announcements during the recent global financial crisis (for reviews see Joyce et al., 2012; Williams, 2014). The majority of this literature is motivated formally or informally by recent theoretical work where the interaction between preferred habitat investors and arbitrageurs is assumed to impact the shape and location of the term structure (see, in particular, Vaynos and Vila, 2009; Greenwood and Vayanos, 2014). In this framework there is scope for central bank asset purchases to affect bond yields through scarcity and duration risk effects.[1] More generally, findings from other studies show that the supply and maturity structure of debt can explain or forecast yields (see e.g. Swanson, 2011; Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood and Vayanos, 2013; Hamilton and Wu, 2012; Li and Wei, 2013; and Kaminska and Zinna, 2014). The bulk of the existing literature, however, has focused on the US, with

[1] Both of these channels come under the general heading of the portfolio balance channel. Signalling is probably the most important of the other channels (see e.g. Bauer and Rudebusch, 2014). The signalling channel relates to the impact asset purchases have on expected future policy rates or, more broadly, on the private sector's understanding of the central bank's monetary policy reaction function. Whatever the importance of signalling effects during the crisis, it is unlikely to have been a material factor in explaining the impact of shocks to the debt structure in the pre-crisis period.

the exception of Afonso and Martins (2010) who looked at the relationship between government debt and yields in Germany, albeit from a different perspective. This paper tries to fill this gap for the euro area and to draw implications for the impact of the ECB's PSPP.

The empirical approach we use involves estimating a small macro-finance model of the euro area economy, incorporating information on the term structure of interest rates, macroeconomic variables, and the debt structure. We proceed in two steps: first, we estimate the latent factors describing the shape of the synthetic euro area yield curve using the Dynamic Nelson Siegel approach (see Diebold and Li, 2006; Diebold, Rudebusch and Auroba, 2006). Second, we estimate a Bayesian VAR (BVAR) that characterises the term structure using the latent factors estimated in the first step and simultaneously relates these factors to observable macroeconomic and financial variables and a measure of net debt supply.

In order to carry out this analysis, we construct a new maturity-weighted measure of net euro area bond supply with a view to capturing primarily changes in duration risk.[2] Our measure uses information on the outstanding debt, its duration and euro area security holdings by foreign official institutions, which are amongst the largest group of investors in euro area bond markets. For example, in Germany at the start of the APP in the second quarter of 2015, foreign central banks held around a third of the total outstanding German central government debt – by far the largest single investor group.[3] By controlling for the amount of bonds held by these relatively price-inelastic institutions that typically are buy-and-hold investors, our measure is more likely to pick up changes in the relevant amount of duration risk held by price-sensitive arbitrageurs, e.g. investment banks, that affects the pricing of government bonds through the so-called duration channel.

Our empirical results provide support for the role of net debt supply effects in the euro area bond market, in line with previous findings for the US and the UK. Exogenous declines in the maturity-weighted amount of government bonds held by price-sensitive private investors lead to a fall in long-term interest rates and a flattening of the yield curve, raising output and inflation with a lag. Using our model results, we find that the PSPP, as announced on 22 January 2015, may have lowered euro area 10-year yields by around 30bps in 2015 and raised the output gap and inflation by around 0.2ppt and 0.3ppt respectively in 2016. These estimates exclude any additional effects of the PSPP on yields and the macroeconomy through the signalling and credit risk channels (see e.g. Altavilla et al., 2015).

The rest of this paper is structured as follows. In Section 2, we provide some theoretical background on the relationship between net debt supply and the term structure. In Section 3 we motivate and describe the derivation of the debt structure variable we use in our

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[2] It is also possible that the measure will pick up some of the effect through the scarcity channel, but that would seem more likely to be evident at the level of different segments of the term structure rather than at the aggregate level.

[3] Credit institutions are the second largest group with an estimated share of 24% in 2015Q2 (see Bruegel, http://bruegel.org/publications/datasets/sovereign-bond-holdings/).

analysis. Section 4 sets out our model and how it is estimated. Section 5 reports our empirical results, including impulse responses, while Section 6 uses the model to infer the effects of the PSPP on the euro area term structure and the implications for the macroeconomy. Conclusions are contained in the final section.

2. Theoretical background

In conventional models of the term structure, net debt supply effects play no direct role in determining yields. In these models, with rational agents, no credit risk and frictionless markets, long-term yields are equal to the average expected future short-term interest rate and a risk premium, where the premium reflects the covariance between expected returns on the bond and the representative investor's stochastic discount factor (intertemporal marginal rate of substitution). Under the consumption CAPM, the risk premium can be linked to consumption growth, so that bonds are valued more if their returns are higher in bad states of the world where marginal utility is higher and consumption growth lower.[4]

Central bank asset purchases can only be effective in this setup if they alter the markets' expectation of the future path of short-term interest rates through the "signalling" channel (see e.g. Eggertsson and Woodford, 2003; Woodford, 2012). By contrast, asset purchases cannot directly affect term premia because the covariance between expected bond returns and marginal utility is unaffected by whether assets are held on the balance sheet of the public or private sector. If the central bank buys assets from the private sector in return for reserves, the private sector's overall risk profile is unchanged since the gains or losses on the public sector's portfolio result in changes in the taxes paid by the private sector. It follows that changes to the structure of government debt would also have no effects, even if these were associated with tax changes (as under Ricardian equivalence). However, the conditions in which asset purchases or the net debt supply are entirely neutral for yields and other asset prices are very restrictive and unlikely to hold in practice.[5]

The view that financial market prices depend in part on the amount of assets held by the private sector goes back to the literature on the portfolio balance channel, associated with the work of Tobin and others (see e.g. Tobin, 1961, 1963 and 1969). The foundation of these effects rests on the idea that, if assets are imperfectly substitutable, a shock to asset stocks will require a change in expected excess asset returns to restore equilibrium. This is consistent with the notion that investors have so-called preferred habitats for certain assets or segments of the yield curve (see Culbertson, 1957; Modigliani and Sutch, 1966). This older literature, however, fell out of favour among many academics and practitioners, primarily due to its lack of microfoundations. But recent theoretical advances (e.g. Andrés et

[4] For a textbook treatment of asset pricing theory, see e.g. Cochrane (2001).

[5] In addition to rationality, Woodford (2012) notes two necessary assumptions: that assets are only acquired for their pecuniary returns (ruling out convenience yield or liquidity motives) and that agents can purchase any asset in any desired amount at given market-determined prices.

al., 2004; Chen et al., 2012), and the adoption of large-scale asset purchases by several central banks during the crisis, have led to a reassessment of the importance of these effects.

One of the most influential recent papers by Vayanos and Vila (VV, 2009) formalises the role of preferred habitat investors in the context of a no-arbitrage model. In their model, there are two types of agents: preferred habitat investors and risk-averse arbitrageurs. The preferred habitat investors are assumed, for simplicity, to demand only zero-coupon bonds of a specific maturity. Arbitrageurs, in contrast, trade across different maturities rendering the term structure arbitrage free. But since arbitrageurs are risk averse (or equivalently capital constrained), they do not completely offset the impact on interest rates of demand or supply shocks from preferred habitat investors. Changes in the net supply of bonds affect the total quantity of duration risk that arbitrageurs hold, which affects the price of duration risk and thereby term premia.[6]

3. Measuring net debt supply

In what follows, we first motivate our preferred measure of net debt supply, before turning to the data used to construct it and developments in this measure over our sample period.

3.1 Conceptual issues

Measuring outstanding duration risk is a difficult task as no public information on the portfolio holdings of arbitrageurs is available. Empirical measures used in the literature are therefore inevitably imprecise. Greenwood and Vayanos (2014) look at a number of measures and find that maturity-weighted debt-to-GDP dominates other measures they consider in terms of forecasting future bond returns. This is the starting point for our own analysis. Using information on the outstanding stock of central government debt and its average residual maturity, we derive a gross maturity-weighted debt measure for the euro area. More formally, we construct maturity-weighted euro area debt MWD_t as:

$$MWD_t = \sum_{i}^{4} D_{i,t} * M_{i,t} \tag{1}$$

where $D_{i,t}$ is the outstanding stock of central government debt in country *i* in period *t* and $M_{i,t}$ is its average residual maturity (where *i* = Germany, France, Italy and Spain).[7]

Although the measure favoured by Greenwood and Vayanos incorporates information on the effective duration of outstanding debt, thereby capturing shifts in the relative supply of long-term to short-term debt available to private investors, it also has important

[6] Their model suggests that the nature of the impact depends crucially on the degree of risk aversion of arbitrageurs (see Vayanos and Vila, 2009, for more detail).

[7] We use central and not general government debt because the January 2015 Eurosystem's PSPP is directed exclusively to central government securities.

shortcomings. In particular, the total stock of debt includes holdings by various buy-and-hold investors, such as pension funds, insurance companies or official institutions (central banks and sovereign wealth funds), which can be very significant. This matters because debt supply shocks are likely to lead to very different bond price responses depending on the degree of absorption by preferred-habitat investors. Given their largely non-pecuniary motives – for example, the institutional need to match assets and liabilities, safety considerations or capital preservation – preferred habitat investors may absorb new bonds without demanding a higher return. Ignoring these holdings would therefore lead to biased estimates of the effects of an increase in maturity-weighted gross debt supply on the term structure of interest rates, as what matters more for bond pricing is the *net* supply of duration held by price-sensitive investors.

Unfortunately, data on government bond holdings by preferred-habitat investors are inherently difficult to obtain. There is no single official source at euro area level and data availability differs widely across national sources. Merler and Pisani-Ferry (2012) made an attempt to collect data across major euro area Member States from national sources, but their database does not sufficiently differentiate between institutions likely to be classified as buy-and-hold investors and those thought to be arbitrageurs. Studies for the United States, by contrast, have mainly used variations in the Federal Reserve's System Open Market Account (SOMA) to infer changes in the amount and duration of bonds held by the private sector as a way of simulating the effects of Quantitative Easing (see e.g. D'Amico et al., 2012; Li and Wei, 2013). However, in the euro area monetary policy security holdings of national central banks and the ECB have been small and static given the collateralised lending nature of monetary policy implementation in the euro area.[8]

Against this background, we follow an approach pursued by Bernanke, Reinhart, and Sack (2004) and Gagnon et al. (2011), who both use foreign official holdings of US Treasury debt as a way to gauge the impact of central bank government bond purchases on the term structure.[9] Because foreign official holdings of US debt grew rapidly in the 2000s, these purchases serve as a natural basis for testing the relationship between changes in net bond supply and interest rates as the response of asset prices should not be affected by the type of public investor, foreign or domestic. Although of equal importance in many euro area Member States, the impact of movements in foreign official holdings of euro area debt on the term structure has so far been largely ignored in the literature, with the exceptions of Andritzky (2012) and Arslanalp and Tsuda (2014) who both conducted cross-country studies, which include the euro area.

[8] Data on bonds held by Eurosystem central banks as part of their non-monetary policy portfolio are not publicly available.

[9] A large related strand of literature examines the effects of changes in the demand of foreign institutions on US bond yields (cf. Warnock and Warnock, 2009; Beltran et al., 2013; Kaminska, Vayanos and Zinna, 2011; and Kaminska and Zinna, 2014).

We therefore exploit data on foreign official holdings provided by the IMF to measure more accurately the amount of duration risk held by private arbitrageurs (see Section 3.2). Our preferred measure of the net maturity-weighted "free-float" takes the following form:

$$FF_t = \frac{MWD_t - \sum_i^4 OH_{i,t} * OHM_{i,t}}{Y_t} \tag{2}$$

where we deduct from MWD_t the sum of the product of foreign official holdings in each country $OH_{i,t}$ weighted by their residual maturity, $OHM_{i,t}$, and divide the total by Y_t, the nominal GDP of our four euro area countries.[10] As foreign exchange holdings are reported by the IMF in market values, we express both total debt and official holdings in market values.[11]

Our weighted free-float measure should provide a better proxy of the duration risk held by private arbitrageurs than the unadjusted stock of euro area bonds, which includes holdings by a large and relatively price-insensitive group of preferred habitat investors. Our measure also takes into account the maturity of official holdings, which might be of particular importance in the context of central bank asset purchases.[12] For example, if official holdings were to be predominately held at the long end of the curve, the effects of an increase in demand by these investors on yields across the maturity space could be stronger as arbitrageurs – for the same quantities – are left with less duration risk in their portfolio and might hence require a lower return on their overall holdings.

However, our measure also comes with some potential drawbacks. For example, an increase in the free-float may be associated with both a sell-off in foreign official holdings (a fall in OH_t) or a debt-financed fiscal expansion through an increase in MWD_t. Although both should be expected to lead to an increase in yields implied by the rise in duration, the fall in output and inflation that this would ultimately trigger would be offset, at least in part, by an increase in government spending in the case of an expansionary fiscal shock. By contrast, the narrow mandate of most foreign official institutions, mainly geared towards capital preservation and/or foreign exchange stabilisation, should make their investment choices largely exogenous to domestic macroeconomic conditions and interest rate levels. We

[10] The use of GDP as a scaling variable follows the recent QE-influenced literature (see e.g. Gagnon et al., 2011, Li and Wei, 2013, etc.). Standard portfolio balance theory would suggest relating asset holdings to wealth, but trends in GDP may provide a good proxy for changes in wealth.

[11] Eurostat's Government Finance Statistics (GFS) database reports debt in market values but for the general government rather than central government. We therefore use daily market prices and outstanding debt obtained from Bloomberg for every bond issued by the four largest euro area central governments over the period 1999 to 2014. Using market prices introduces the risk that our free-float measure is, by construction, correlated with yields. Greenwood and Vayanos (2014), however, point out that endogeneity could also arise if we were to use face value data. Using instrumental variables, they show that the results are unaffected by the choice of face or market value.

[12] As we argue in more detail below, although the PSPP is intended to be "market neutral", purchases are restricted to have a minimum maturity of two years, and may in practice be tilted towards the longer-end of the maturity spectrum given the ECB's lower rate threshold for purchases at the deposit facility rate. The available evidence on the average maturity of ECB purchases confirms this conjecture. Up to April 2015, ECB purchases of government bonds had an average maturity of 8 years, higher than the average maturity of total outstanding bonds of 6.6 years, implying a shift in the relative supply of long-term to short-term debt available to private investors.

therefore check the robustness of our main results to including (maturity-weighted) debt and (maturity-weighted) official holdings separately in the model (see Section 5.2 and Annex 2). In addition, we choose the calibration of priors in our Bayesian estimation strategy with a view to limiting the effects on the macroeconomy coming from shocks to our free-float measure to those that come through the impact on the term structure of interest rates (see Section 4).

3.2 Measurement issues

We use the IMF COFER (Currency Composition of Official Foreign Exchange Reserves) database and the Coordinated Portfolio Investment Survey (CPIS) to construct our time-series on foreign official holdings. The COFER reports quarterly end-of-period data on the currency composition of global foreign exchange holdings, without providing a breakdown by issuer country of reserves allocated to the euro (or for any of the other major currencies). The CPIS, meanwhile, provides a detailed country breakdown of annual (from 2013 onwards bi-annual) data on securities held by foreign official institutions. Following the methodology suggested by Arslanalp and Tsuda (2012), we use the data from the CPIS to estimate the share of total euro reserves that can be attributed to the four largest euro area countries in the COFER database.[13] By combining these two sources, we are able to compute a quarterly time series of euro area bonds held as reserve assets with a view to approximating better variations in the amount of euro area bonds held by private arbitrageurs.

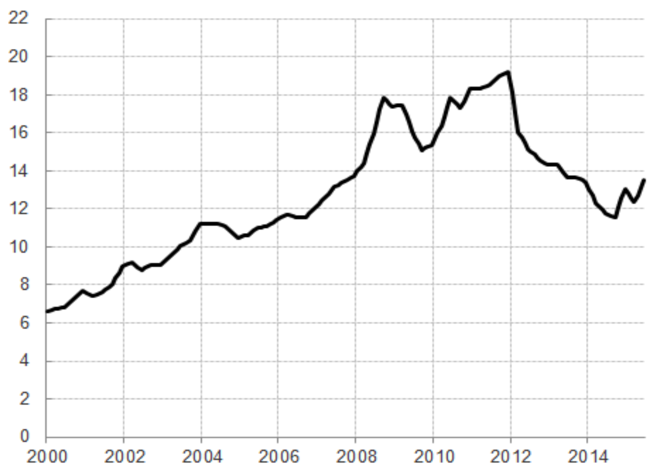
Doing so is not possible without making a number of assumptions. First, we assume that 80% of foreign exchange reserves reported under COFER are held in government bonds, consistent with the findings by Arslanalp and Tsuda (2012).[14] Second, we only consider reserves that have been allocated to the euro. Compared to the IMF's International Financial Statistics (IFS), the COFER covers only about half of total foreign exchange reserves, with some countries withholding information about the currency composition of their foreign exchange reserves. We ignore reserves where we have no information on their currency composition, except in periods where there is a large discrepancy between the

[13] Strictly speaking, the information comes from the Survey of Geographical Distribution of Securities Held as Foreign Exchange Reserves (SEFER) survey that is integrated into the CPIS. Unfortunately, some important foreign exchange holders, such as China and the United Arab Emirates, do not participate in the CPIS survey.

[14] Foreign exchange reserves reported under COFER may be in the form of foreign banknotes, bank deposits, treasury bills, short- and long-term government securities, and other claims usable in the event of balance of payments needs (see http://data.imf.org/?sk=E6A5F467-C14B-4AA8-9F6D-5A09EC4E62A4). In the SEFER, holdings of debt securities can be singled out.

CPIS survey and the COFER.[15] Third, from 1995 to 1998 COFER has the share of reserves held in the national legacy currencies of the euro. Given that the CPIS only starts in 2001, we reconstruct the values for 1999 and 2000 by creating a time series path that would match the share of legacy currencies in total euro reserves at the end of 1998 with that provided by the CPIS for 2001.

Figure 1. Euro area bonds held as reserve assets
(as % share of total outstanding central government debt)



Sources: IMF COFER, CPIS, Bloomberg, Haver, Eurostat and author calculations.

Figure 1 shows the resulting measure of euro area bonds held as reserve assets, expressed as a share of total central government debt.[16] The series reveals two distinct phases. First, from 2000 to 2012, there was a strong upward trend in the share of official holdings of euro area debt, rising from around 7% to close to 20% of total outstanding debt, reflecting in particular at the early stages a strong surge in holdings of debt issued by Member States with legacy currencies other than the Deutsche Mark: with the euro having become an international reserve currency, portfolio diversification implied a relative shift in reserve allocation to debt issued by France and, to a lesser extent, Italy and Spain, although holdings of German central government debt also continued rising at a fast pace. This trend was interrupted only during the global financial crisis in 2009, when holdings were reduced abruptly in a flight to safety while debt issuance surged. Second, with the intensification of the sovereign debt crisis in 2012, there was a marked decline in the share of official holdings

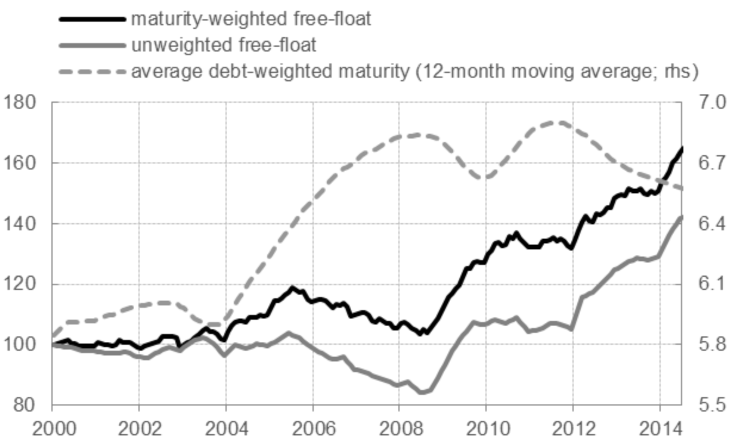
[15] In 2007-08, the CPIS reported a large increase in foreign holdings of euro area debt securities, at odds with the COFER data, which showed only a marginal increase. Because the number of reporting economies in the CPIS remained unchanged over this period, the discrepancy can be either explained by foreign official institutions devoting a larger-than-usual share of their allocated reserves to debt securities or a strong increase in unallocated reserves to the euro. Given that the global financial crisis led to a sell-off in bonds in 2008, we contemplate that unallocated reserves are likely to account for the difference. In 2009, by contrast, allocated reserves rose sharply, while the CPIS reported steady holdings. Here we believe that a large share of allocated reserves have been invested in instruments other than debt securities.

[16] The monthly series was interpolated from the quarterly series with a cubic spline.

to just below 12% of central government debt, mainly reflecting a type of "fire-sale" of euro area debt by foreign official institutions (with the exception of German debt). However, from the middle of 2014 this trend was reversed and official holdings of euro area debt started to recover at slow pace.

To measure the duration extracted by foreign official institutions – information that is typically classified – we make use of data available for the US. Annual data from the Treasury International Capital (TIC) reporting system show that, on average in 2004-2014, nearly 60% of foreign official holdings of US Treasuries were held in the 1-5-year maturity bucket, and some 23% in the 5-10 year segment, with an average maturity of four years.[17] Moreover, foreign official institutions tend to change their duration exposure only marginally over time: the annual standard deviation of the average maturity over the same period was less than two months, ranging from a low of 3.8 years (in 2005) to a high of 4.2 years (in 2012). This strong preference for a certain duration exposure is consistent with foreign official institutions being thought of as preferred-habitat investors. In computing our maturity-weighted free-float measure, we assume that foreign official holdings of euro area bonds also have a constant average maturity of four years over our sample, reflecting the similar mandates of foreign official institutions, as well as the broad similarities between the core euro area and Treasury markets.

Figure 2. Weighted and unweighted "free-float" measures and the average maturity of debt *(as a share of GDP except maturity, which is in years; left-hand axis: index: Jan-2000 = 100; right-hand axis: years)*



Sources: Bloomberg, national debt management offices and author calculations.

Figure 2 shows our weighted free-float measure relative to an unweighted counterpart (which can be thought of as the case where $M_{i,t}$ and $OHM_{i,t}$ in equations (1) and (2) are set

[17] See http://www.treasury.gov/resource-center/data-chart-center/tic/Pages/fpis.aspx for a summary of recent reports. The maturity structure of foreign official holdings is only available from 2004.

equal to 1).[18] We focus first on the period 2004-2007. During this period, official holdings of euro area bonds rose rapidly (cf. Figure 1), thereby reducing the free-float and presumably putting downward pressure on yields as arbitrageurs were left with less duration risk on their balance sheets. However, a steady increase in the average maturity of outstanding bonds over the same period will have tended to offset this effect. This can be seen by the diverging developments in the weighted and unweighted measure: while in late 2007 the former was up by around 5% compared to early 2004, the latter was down by 10%. In other words, unless foreign official institutions increased their duration exposure during that period – a hypothesis that US TIC data reject – the impact on euro area yields resulting from a fall in the free-float should have been more muted given the increase in average duration. The observed opposite effects are likely to have occurred during the period of sell-off in official holdings in the wake of the outbreak of both the global financial crisis and the sovereign debt crisis – periods that coincided with a reduction in the average maturity of euro area bonds, probably owing to partially reduced market access as well as the need of governments to raise large sums of funds in a short period of time. In these cases, the reduction in the average maturity of outstanding debt is likely to have offset the increase in the free float, reducing the upward pressure on yields.

4. A macro-finance model with debt supply

Our estimation strategy proceeds in two stages. In a first step, we estimate the latent yield curve factors using the Dynamic Nelson-Siegel (DNS) approach developed by Diebold and Li (2006) and Diebold et al. (2006). In the second step, we estimate a Bayesian VAR, which includes the yield curve factors, three macroeconomic variables (the output gap, CPI inflation and the euro nominal effective exchange rate) and our measure of the net supply of government securities available to market participants. We use a two-step approach – compared to the alternative of estimating the yield curve factors and the other variables jointly in a state-space model – due to the well-known difficulties of maximum-likelihood estimation of large state-space models with many factors and highly persistent interest rates.[19]

We estimate the DNS yield curve factors from the synthetic debt-weighted term-structure of the four largest euro area Member States, using an exponential approximation to the cross-section of yields:

[18] For central government debt, we obtain information on the maturity profile from Bloomberg and the relevant debt management offices to get a weighted measure of the outstanding debt stock.

[19] We use yield curve factors generated from a DNS model and not following a no-arbitrage approach also largely on grounds of tractability. Estimation of an affine term structure model would not be helped by the relatively small size of our sample. As illustrated by Kim and Orphanides (2012), estimates of the market price of risk in no-arbitrage models suffer from a severe small-sample problem due to (near) unit-root behaviour of interest rates. Also, in our context, the distinction between the effects on term premia and the expected path of short-term rates should be largely irrelevant as historically movements in our free-float measure are likely to be independent of monetary policy expectations (see also Bernanke, Reinhart and Sack, 2004). Thus, any impact on the yield curve through changes in net bond supply that we identify can be expected to reflect changes in the term premia.

$$y_t(\tau) = \beta_1 + \beta_2\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau}\right) + \beta_3\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right) \quad (3)$$

where $y_t(\tau)$ are (zero coupon) yields of maturity τ. In order to derive the yield factors, we put the model in state-space, where the measurement equation relates yields to the three unobservable yield factors and a vector of measurement errors, and the factors are generated by a first-order VAR:

$$y_t(\tau) = \varphi * f_t + e_t \quad (4)$$

$$f_t = c + A * f_{t-1} + v_t \quad (5)$$

where f_t holds the three DNS factors, φ is the corresponding loading matrix, c is a vector of constants, and A contains autoregressive parameters that characterise the dynamic evolution of the factors. The vectors e_t and v_t are error terms, which are assumed to be white noise and uncorrelated. We can then obtain the yield curve factors as the Kalman-filtered state variables.

We estimate the state space system over the sample January 2000 to April 2013, using government bond yields for maturities of 24, 36, 48, 60, 72, 84, 96, 108 and 120 months as provided by Reuters. By restricting the sample to the period of positive policy rates, i.e. until April 2013, we should reduce the risk of running into potential zero-lower-bound biases that arise from the difficulty of fitting the distribution of yields when rates are at, or close to, zero.[20]

In the second step, we model the dynamics of the yield curve factors, the macroeconomy and our debt supply measure jointly in a VAR:

$$X_t = \sum_{j=1}^{p} A_j * X_{t-j} + k + \varepsilon_t \quad (6)$$

where X_t is a M x 1 vector containing observations on the M endogenous variables, A_j is a M x M matrix of coefficients, k is a M x 1 vector of intercepts, and ε_t is an M x 1 vector of errors following a multivariate normal distribution $\varepsilon_t \sim N(0,\Sigma)$. In matrix notation, equation (6) can be conveniently expressed in transpose form as:

$$X_t' = \sum_{j=1}^{p} X_{t-j}' * A_j' + k' + \varepsilon_t' \quad (7)$$

[20] German and French yields fell below zero even before policy rates became constrained by the lower bound, mainly reflecting flight-to-safety capital flows. The premise here, however, is that bond markets might only change their behaviour once the policy rate has hit the effective lower bound and the next policy move can only be up. We therefore constrain our estimation to the sample when the ECB's main refinancing rate was still at 75bps, with room for further rate cuts. Indeed, the recent episode of negative official rates, and deep negative Bund yields, even questions the constraints put by the zero-lower bound. Shadow rate models are an alternative modelling device to overcome potential issues at the lower bound (see Christensen and Rudebusch, 2013, and Lemke and Vladu, 2014).

As the model holds for any t, the observations can be stacked to reformulate the model for the whole dataset. Then gathering terms, we get the following compact notation:

$$X = ZB + E \tag{8}$$

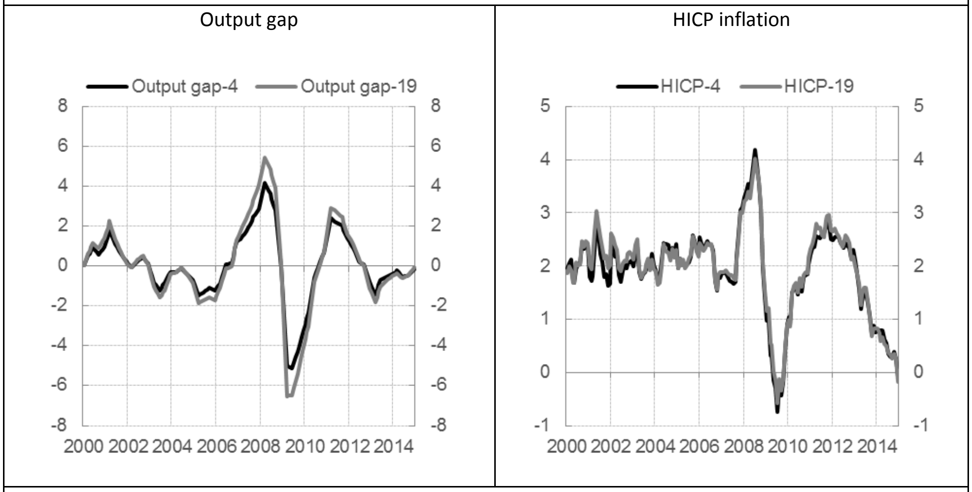
where $X = \left[X_1^{'}\; X_2^{'} \dots X_T^{'}\right]'$, $B = [A_1'\; A_2' \dots A_p'\; k']'$, $E = [\varepsilon_1'\; \varepsilon_2' \dots \varepsilon_T']'$ and

$$Z = \begin{pmatrix} X_0' & X_{-1}' & \cdots & X_{1-p}' & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ X_{T-1}' & X_{T-2}' & \cdots & X_{T-p}' & 1 \end{pmatrix}$$

In our case we have seven endogenous variables (M=7). The macroeconomy is represented by two key variables: the output gap and the inflation rate. The output gap is estimated by applying the Hodrick-Prescott (HP) filter to the sum of real GDP in the four economies, with a restriction parameter λ equal to 14,400 (the value typically used for monthly data). For inflation, we use the annual growth rate of the consumption-spending-weighted seasonally adjusted harmonised consumer price index of the four Member States. Because the four countries account for around 75% of the output of the currency union, our weighted output and inflation measures behave in a very similar way to the total aggregate euro area counterparts (Figure 3). The short-term interest rate is the 3-month Euribor, which links the macroeconomy to the term structure of interest rates. To avoid multi-collinearity in the estimation, we only include the short-term rate, the slope factor and the curvature factor, which allows us to back out the impact on the level factor. Including the slope factor in a model of the macroeconomy, and in particular in one characterised by strong bank intermediation, has the additional advantage of capturing growth and inflation effects that may arise from the incentives of banks to engage in maturity transformation. Given that bond transactions by foreign official institutions might also affect the foreign exchange market, we also include the nominal effective exchange rate of the euro.

Our measure of debt supply is the one presented in Section 3. It enters the model in levels. A caveat of our model setup is that, in theory, what matters for the pricing of bonds is the expected future net supply of the asset, not its current or past values. This assumption is grounded on the conjecture that markets are forward-looking in their pricing of financial instruments. VARs, however, are not in general well-equipped to handle the forward-looking nature of asset prices. This is a well-known problem in the VAR literature. For example, the implausible response of inflation to a monetary policy shock (the “prize-puzzle”; cf. Sims, 1992) has often been associated with a failure to account for expectations in the setting of monetary policy (Brissimis and Magginas, 2006). Similarly, Ramey (2011) shows that big increases in fiscal spending are anticipated several quarters before they actually occur, which can help explain differences in empirical findings on the impact of fiscal shocks on output and wages.

Figure 3. Output gap and inflation measures
(per cent)



Notes: Output gap-4 and HICP-4 refer to the weighted measures of Germany, France, Italy and Spain. All series are seasonally adjusted. The output gap is estimated by using the HP-filter with λ equal to 14.400. Inflation is the annual rate of change in the HICP.

One way to overcome this problem would therefore be to include variables that may provide useful information on the future path of net bond supply. But given the opacity of foreign central banks (and for that matter any preferred-habitat investor) in their allocation of funds as well as the absence of high-frequency data on expectations of future bond issuance, predicting movements in our free-float measure in real-time is far from simple, including for financial market participants. In other words, unlike the literature on monetary or fiscal policy shocks, in our framework it is inherently difficult to include a coherent measure of expectations of the future net bond supply to help obtain a more realistic account of the information available to markets to price bonds.[21] This implies that, although our estimates are derived using the actual (and not expected) net supply of bonds, the innovations to our free-float measure can be interpreted as random shocks given the considerable informational frictions.

We estimate the model using Bayesian methods over the period 2000 to April 2013.[22] The advantage of using a Bayesian approach is that it allows us to combine prior information about the distribution of the model parameters (the prior distribution) with the information contained in the data (the likelihood function) to obtain the posterior distribution. In

[21] Indeed, the large number of fiscal instruments and their uncertain effects on the economy make the forecasting problem challenging for markets. For simplicity, fiscal deficits are often used to forecast future bond issuance. However, official deficit projections, such as from the European Commission or the IMF, are only published bi-annually. A simple approach to help overcome this constraint would be to include forecasts for output and inflation but this would not help the identification of expected future foreign central bank purchases – a critical driver of our free-float measure. Also, the inclusion of the contemporaneous output gap, as in our VAR, might by itself already encapsulate sufficient information for markets to forecast future fiscal deficits (cf. Hagemann, 1999).

[22] We are grateful to Dieppe et al. (2016) for making their Matlab code available to us.

general, for a vector of parameters θ and a data set y, Bayes rule implies the following formula:

$$\pi(\theta|y) = \frac{f(y|\theta)\pi(\theta)}{f(y)} \tag{9}$$

where $\pi(\theta|y)$ is the posterior distribution of θ conditional on y, $f(y|\theta)$ is the conditional likelihood, $\pi(\theta)$ is the prior distribution of θ and $f(y)$ is the density of the data. Since the density is independent of θ, it is convenient to ignore it and rewrite the expression as:

$$\pi(\theta|y) \propto f(y|\theta)\pi(\theta) \tag{10}$$

which states that the posterior distribution is proportional to the likelihood times the prior. In our case, θ will include two blocks: one containing the VAR parameters B and the other the residual variance-covariance matrix Σ. For the former we assume a multivariate normal distribution, i.e.

$$\pi(\beta) \sim N(\beta_0, \Omega_0) \tag{11}$$

with mean β_0 and covariance matrix Ω_0 and where $\beta = vec(B)$. To estimate β_0 and Ω_0, we follow the strategy proposed by Litterman (1986) and assume that the prior mean of coefficients of the first lag is equal to 1 and the prior mean of coefficients for further lags and cross-variable lags is equal to zero.[23] Further, we assume that Ω_0 is diagonal, where the diagonal elements are given by:

$$\sigma_{ij}^2 = \begin{cases} \left(\lambda_1 / l^{\lambda_3}\right)^2 & if\ i = j \\ \left(\lambda_1 \lambda_2 \lambda_5 \sigma_i / l^{\lambda_3} \sigma_j\right)^2 & if\ i \neq j \\ (\lambda_1 \lambda_4 \sigma_i)^2 & if\ i = c \end{cases} \tag{12}$$

where $\lambda_1 = 0.2$ determines the tightness around the variance of the own lag, $\lambda_2 = 0.3$ the tightness of cross-variable lags, $\lambda_3 = 2$ is a parameter controlling the decay over time and $\lambda_4 = 100$ controls the tightness around the constant, c. These priors are standard ones in the literature. λ_5 deserves further explanation. We set this parameter equal to one for all elements, except for the variance of our free-float measure in the output gap and inflation equations, where we set $\lambda_5 = 0.01$. By forcing the posterior value of our free-float measure to be close to zero in these instances, we ensure that changes in the debt supply will mainly affect output and inflation through the implied changes in the term structure of interest rates and not through other channels, which might arise in the case of a debt-financed

[23] Give that we include the net bond supply measure in levels we assume a prior of one as one would do if a unit root is suspected. Our posterior estimates, however, are not affected by our choice of the prior mean for the first lag.

expansion of fiscal policy.[24] Finally, ${\sigma_i}^2$ and ${\sigma_j}^2$ denote the OLS residual variances of an auto-regressive model previously estimated for variables *i* and *j*.

For the variance-covariance matrix Σ we assume an inverse Wishart prior:

$$\pi(\Sigma) \sim IW(S_0, \alpha_0) \tag{13}$$

where S_0 is a matrix of dimension M x M and α_0 is the number of degrees of freedom. Following Karlsson (2012), we define S_0 as follows:

$$S_0 = (\alpha_0 - M - 1)\begin{pmatrix} \sigma_1^2 & 0 & 0 & 0 \\ 0 & \sigma_2^2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \sigma_M^2 \end{pmatrix} \tag{14}$$

and set $\alpha_0 = M + 2$, where σ_i^2 are obtained from individual AR regressions.

The choice of our prior structure for β and Σ implies that no analytical solution is available for the unconditional marginal distribution of Σ. We therefore use numerical methods (Gibbs sampler) to sample from the known conditional marginal distribution to obtain the unconditional posterior distribution (see e.g. Greenberg, 2008). Our results are based on 10,000 iterations of the Gibbs sampler with the first 2,000 discarded as burn-in sample. Finally, we use the marginal likelihood of the model to determine the optimal lag length. We estimate the model with up to six lags and conclude that the marginal likelihood is largest for a model with two lags.

5. Estimation results

We first present the estimates of our Nelson Siegel state space model before we discuss in detail the results and properties of the BVAR. We examine forecasting properties, impulse response functions and historical variance decompositions.

5.1 Yield curve estimates

The DNS model fits our synthetic euro area yield curve data remarkably well. Table 1 shows the mean measurement errors and their standard deviations in basis points, computed using the Kalman smoother estimates.[25] The mean errors are less than one basis point at all maturities, exhibiting only small deviations.

[24] See also the discussion in Section 3 and 5.2 and related sensitivity analysis in Annex 3.

[25] Annex 1 shows the actual and fitted values for selected maturities.

Table 1. Measurement errors of yield equations *(in bps)*

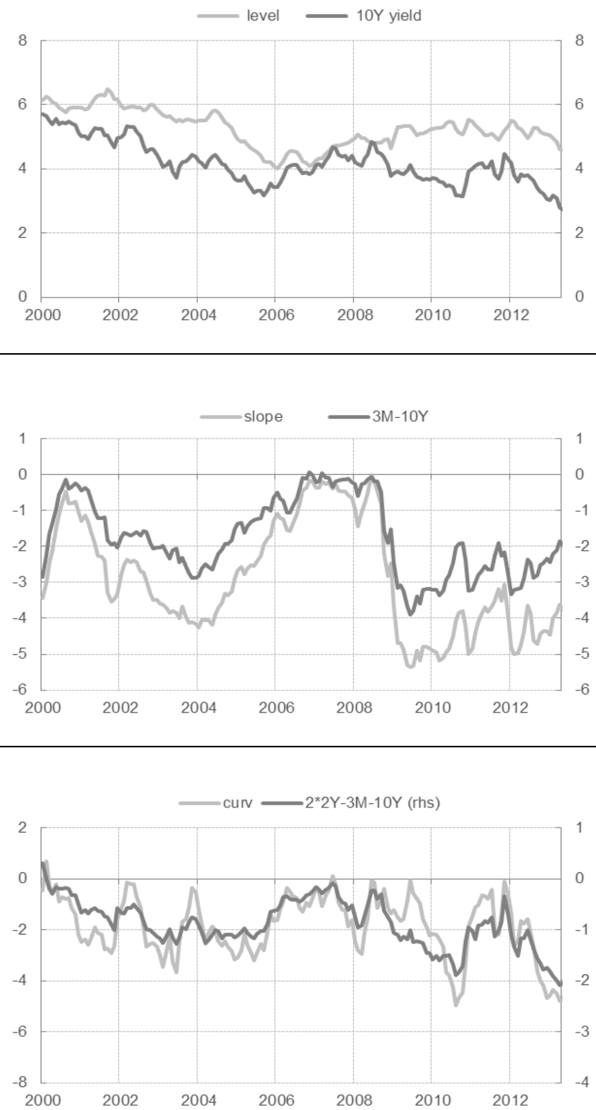
Maturity	Mean	Std. Dev.
24	0.33	5.35
36	-0.63	3.01
48	0.90	3.85
60	-0.10	1.74
72	-0.01	2.95
84	0.14	2.69
96	0.49	1.93
108	-0.29	1.76
120	0.32	4.48

Notes: The table shows the mean measurement errors of the yields using the Kalman smoother estimates over the sample 2000 to April 2013.

We use the Kalman smoother to extract the latent yield curve factors. The upper panel in Figure 4 shows the latent level factor and the 10-year yield series. The correlation between the two series is around 70% over the period 2000 to April 2013, lending support to the interpretation of the first factor as the level factor. The middle panel shows the smoothed estimate of the slope factor together with an empirical proxy for the yield curve slope, i.e. the difference between the three-month and ten-year yield. The two series move closely together, with a correlation close to unity.[26] Finally, in the lower panel we show the estimate of the curvature factor together with a proxy, which is calculated as 2*y(2Y)-y(3M)-y(10Y). Also here the correlation is very high, around 80% over the sample, confirming our hypothesis that the third state factor can be interpreted as the curvature factor.

[26] The slope factor also tends to mirror closely developments in the output gap (with a correlation of nearly 60%), suggesting a close link between the yield curve and macroeconomic activity, as highlighted by Diebold et al. (2006).

Figure 4. Latent yield curve factors and their empirical proxies *(%)*

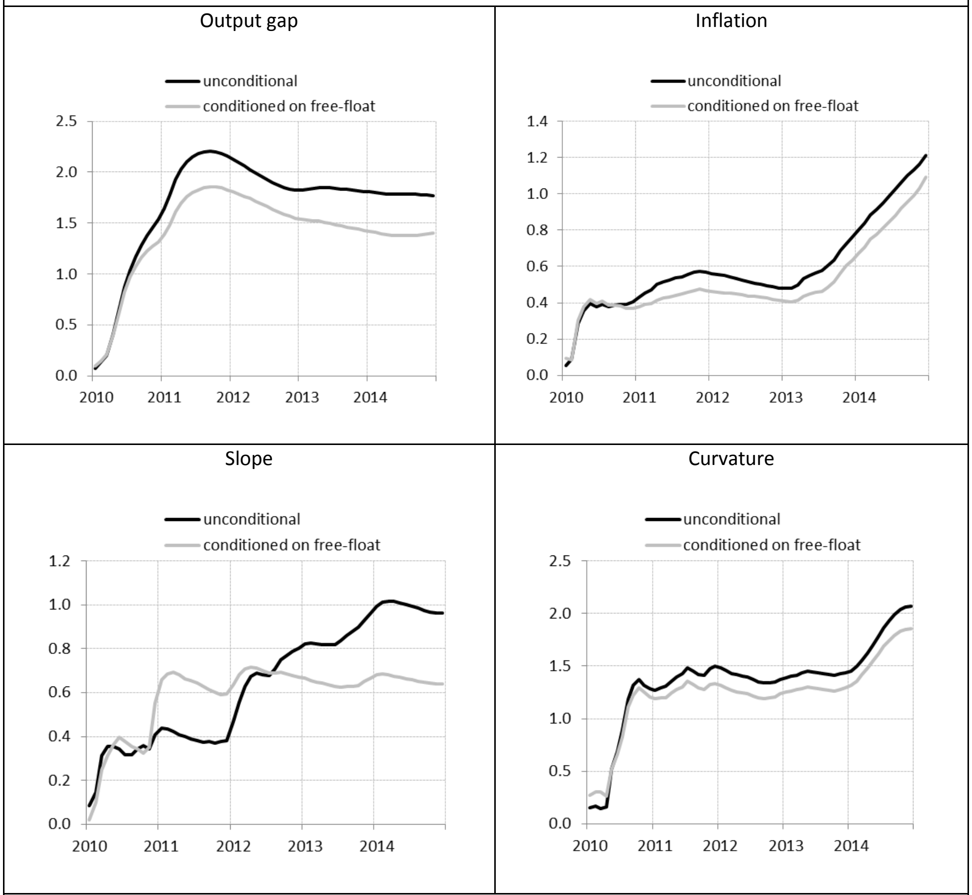


Note: Latent yield curve factors as extracted from the state space model using the Kalman filter. We derived the estimate of the 3m yield from the estimated Nelson-Siegel model.

5.2 BVAR model estimates

We use the latent yield curve factors in a small macro-finance BVAR of the euro area (see Section 4). We begin our analysis by examining the forecasting properties of our BVAR model. For this purpose, we examine the ability of the model to predict outturns both in- and out-of-sample by conducting dynamic conditional forecasts for key model variables over the period 2010 to 2014. We start the forecast 40 months before the end of the estimation sample and extend it for 20 months thereafter. Our objective is to test whether our free-float measure improves the predictions of the model and to inspect the forecasting ability of the model conditional on the actual path of our free-float measure.

Figure 5. Rolling RMSE for conditional model projections
(units)



Notes: RMSE derived once for the unconditional forecast of the model and once for the model that is conditioned on our free-float measure.

Figure 5 plots the rolling Root Mean Squared Error (RMSE) for key model variables over our forecast horizon, once for the unconditional forecasts of our model and once for the model that is conditioned on our free-float measure. It shows that once we add information on the debt structure, model projections for both output and inflation and the term structure improve, often consistently over the entire forecasting horizon, and in particular for longer horizons.[27] In other words, although we limit the direct effect from the free-float measure on the macroeconomy by imposing tight priors around the cross-variable coefficients in this context (cf. Section 4), the debt structure seems to embody valuable additional information for forecasting movements in yields, and, in turn, output and inflation.

We now examine the dynamic responses of macro and financial variables to two different types of shock: a monetary policy shock and a net debt supply shock. We use a Cholesky

[27] An exception is the forecast of the slope factor in 2011, which reflects the sharp flattening of the curve as a result of the sovereign debt crisis, with short-term yields increasing by more than long-term rates. During this period, foreign official institutions reduced their holdings of euro area debt instruments markedly, thereby adding duration to the market, which the model associates with a steepening of the curve.

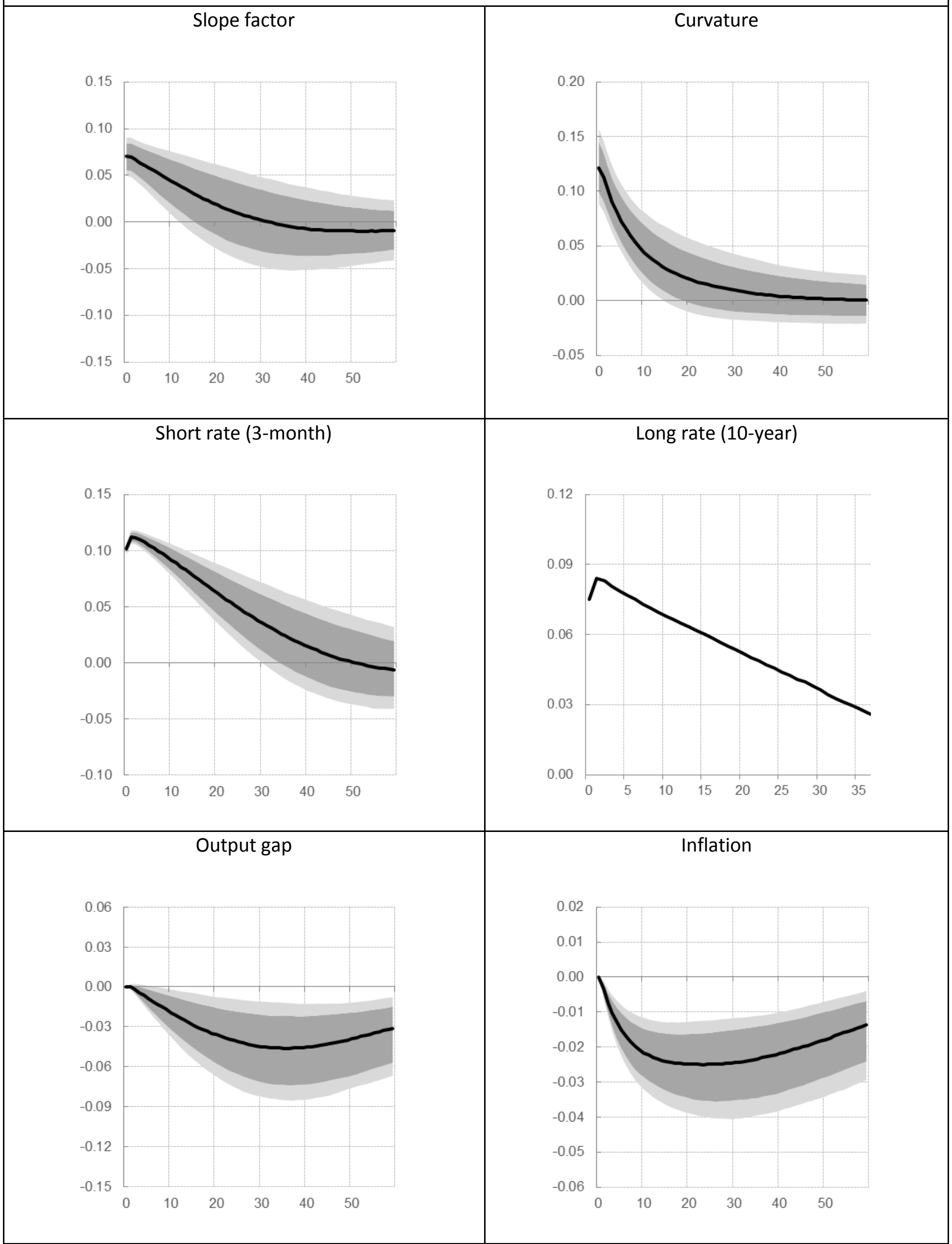
triangular decomposition of the variance-covariance matrix, with the order of our variables reflecting the consensus in the macro-VAR literature that (both short- and long-term) interest rates affect inflation and output only with a lag, while monetary policy may react contemporaneously to macroeconomic shocks (see e.g. Sims, 1980; Christiano et al., 1999; Peersman and Smets, 2001). The exchange rate is ordered last and is therefore allowed to respond contemporaneously to both macroeconomic news as well as movements in the term structure. Equation (15) summarises our identification structure:

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\alpha_{\pi y} & 1 & 0 & 0 & 0 & 0 & 0 \\ -\alpha_{ry} & -\alpha_{r\pi} & 1 & 0 & 0 & 0 & 0 \\ -\alpha_{ffy} & -\alpha_{ff\pi} & -\alpha_{ffr} & 1 & 0 & 0 & 0 \\ -\alpha_{sy} & -\alpha_{s\pi} & -\alpha_{sr} & -\alpha_{sff} & 1 & 0 & 0 \\ -\alpha_{cy} & -\alpha_{c\pi} & -\alpha_{cr} & -\alpha_{cff} & -\alpha_{cs} & 1 & 0 \\ -\alpha_{fxy} & -\alpha_{fx\pi} & -\alpha_{fxr} & -\alpha_{fxff} & -\alpha_{fxs} & -\alpha_{fxc} & 1 \end{bmatrix} \begin{bmatrix} u_t{}^{y} \\ u_t{}^{\pi} \\ u_t{}^{r} \\ u_t{}^{ff} \\ u_t{}^{s} \\ u_t{}^{c} \\ u_t{}^{fx} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \eta_t{}^{y} \\ \eta_t{}^{\pi} \\ \eta_t{}^{r} \\ \eta_t{}^{ff} \\ \eta_t{}^{s} \\ \eta_t{}^{c} \\ \eta_t{}^{fx} \end{bmatrix} \quad (15)$$

We place our debt supply measure after the policy-controlled short-rate and prior to the term structure and the exchange rate. By doing so, we allow net debt supply shocks to affect the term structure and the foreign exchange market instantly. To help with the identification of the shocks, we use monthly averages of yields, which should better reflect movements in bond prices induced by supply or demand shocks than end-of-month yields, which may be prone to outliers and other daily news shocks. Moreover, by placing yields after our free-float measure, we allow yields to move contemporaneously in response to a shock to the free-float. At the same time, by imposing this order, we also reinforce our preferred-habitat assumption as foreign official institutions cannot react contemporaneously to changes in the term structure. This is also consistent with the guidelines published – for example – by Germany's debt management office that its issuance calendar "usually does not ideally supplement the existing debt portfolio in terms of the Federal Government's interest cost".[28]

[28] See http://www.deutsche-finanzagentur.de/en/institutional-investors/portfolio-management.

Figure 6. Impulse responses to a monetary policy shock
(one standard deviation shock)



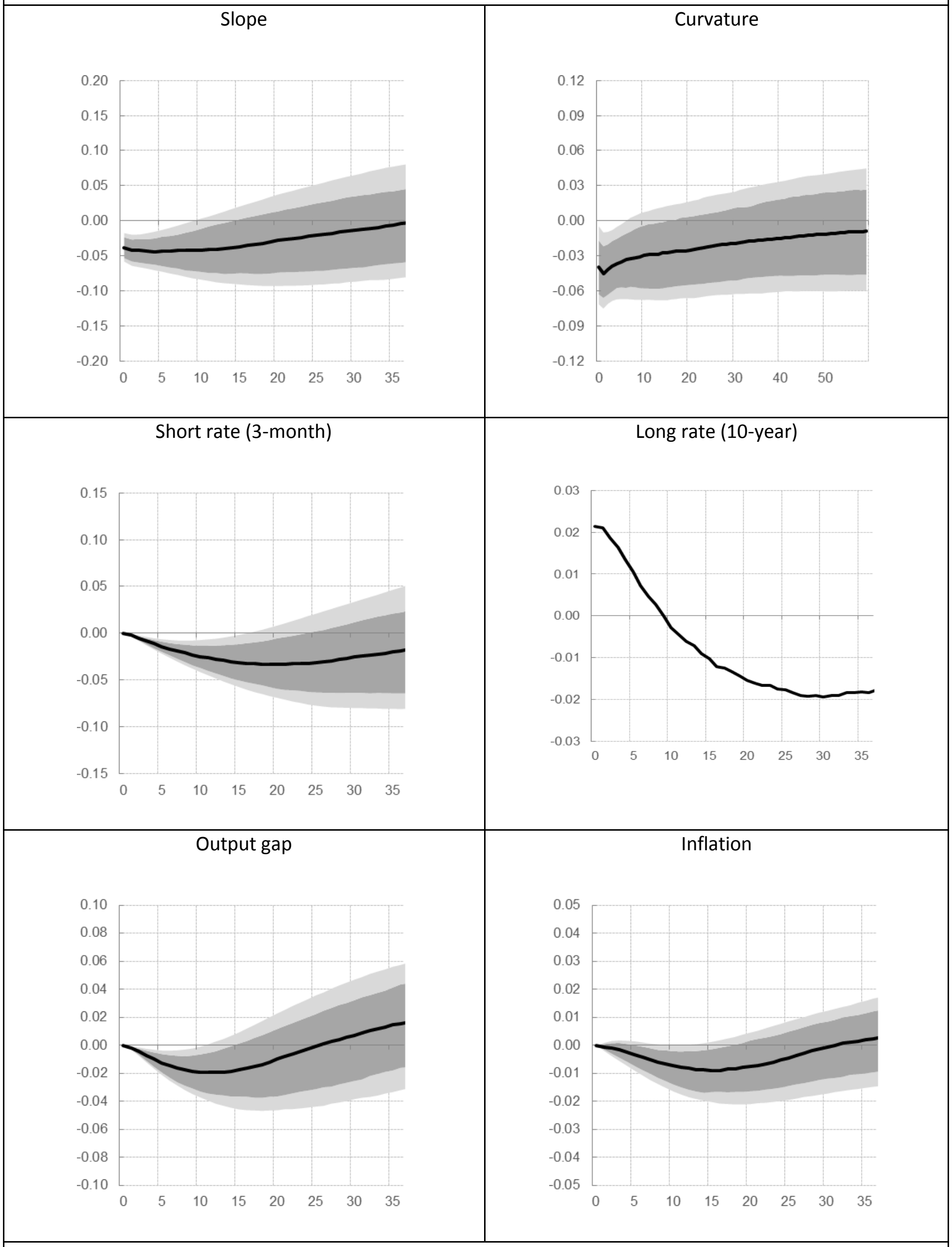
Note: The black solid line is the median estimate. The dark (light) grey shaded area denotes the 50th (66th) percentile confidence band respectively.

We start with the analysis of a standard positive monetary policy shock, which confirms conventional expectations about its transmission to the yield curve and broader economy (Figure 6). The rise in the short rate leads to the expected flattening of the yield curve – the positive hump-shaped response of the slope – as short rates rise faster than long rates.[29] At the same time, the curve becomes more concave, raising the expected return of

[29] The slope factor here is the negative of its empirical proxy.

intermediate bonds, similar to findings by Bekaert et al. (2010). The right-hand panel in the middle row shows how the monetary policy shock transmits along the yield curve using the term structure implied by the factors in our Nelson Siegel state space model: 10-year yields are estimated to rise by about three-quarters of the rise in short-term rates in the peak. Finally, the increase in both short- and long-term rates causes a persistent fall in both output and inflation

Figure 7. Impulse responses to a debt structure shock
(one standard deviation shock)



Note: The black solid line is the median estimate. The dark (light) grey shaded area denotes the 50th (66th) percentile confidence band respectively. The long rate has been computed by running the Nelson Siegel state space model with the impulse response functions of the factors.

We now turn to the analysis of a debt structure shock (Figure 7). All responses have the expected pattern. An increase in the "free-float" is associated with an increase in the amount of bonds in the hands of private market participants (arbitrageurs), therefore lifting the return they require for holding a larger portfolio. As a result, the yield curve steepens as long-term interest rates rise (upper-left panel and middle-right panel). The curvature, meanwhile, falls in parallel with the inverse of the slope, making the curve less concave. And with long-term rates higher, both inflation and output fall (lower panel). Monetary policy reacts to the fall in inflation and output by reducing the short rate with a lag (middle left-hand panel), which stabilises the economy by offsetting the rise in the long rate.

To investigate the robustness of our results, we examine the impulse responses from a number of different specifications, priors and identification schemes. To begin with, we check the sensitivity of our results to the use of our free-float measure by re-estimating the model with maturity-weighted foreign official holdings and debt supply included separately. The charts in Annex 2 show the impulse response functions for this model. The earlier results are by and large confirmed: a (positive) shock to the stock of foreign official holdings reduces the duration held by private arbitrageurs, pushing long-term rates lower, thereby causing a flattening of the curve, which stimulates demand and raises inflation (see Figure A2). The increased demand for domestic bonds by foreign investors leads to the expected appreciation of the NEER. Similarly, a (positive) shock to maturity-weighted debt (see Figure A3) increases the duration held by private arbitrageurs, pushing long-term rates higher, leading to a steepening of the curve, with a concomitant fall in both output and inflation. The increase in long-term rates is, however, moderated by a sharp parallel reduction in the curvature.

We also examine how the choice of different priors affects the results relative to our baseline model. In Annex 3 we show the effect of imposing the restriction that $\lambda_5 = 1$. In this case, the impact of a free-float shock on the term structure is virtually identical, while the impact on inflation is somewhat more marked and more persistent, likely reflecting factors other than the duration channel. Output is only marginally affected by the choice of our priors, which suggests that a free-float shock is unlikely to be related to a debt-financed fiscal expansion shock, as also confirmed in the model where debt was included separately. Figure A4 also shows impulse response functions for looser priors on λ_1 and λ_2.

Finally, we test the robustness of our results to a different identification scheme. Specifically, we try to identify our free-float shock using sign and zero restrictions (Table 2). In doing so, we remain agnostic about our free-float shock: we only impose a positive reaction of the free-float variable for $k=0,\ldots,11$ periods following the shock, i.e. for four quarters, ruling out short-lived changes to the net supply of debt.[30] In addition, we require the response of output and inflation to be zero on impact, thereby reducing the odds that a shock to our free-float variable is a debt-financed fiscal policy shock. Importantly, we leave

[30] Our results are only marginally affected by this assumption as an unrestricted free-float shock tends to be relatively persistent.

both the response of the term structure (at all horizons) and the response of the macroeconomy (in all periods except *k=0*) unrestricted. The other shocks that we identify are a monetary policy shock and a term premium shock.[31] For the latter, we require the long rate to rise by imposing a steepening of the slope and a zero effect of the short rate on impact. Inflation is restricted to fall after a term premium shock (see e.g. Laforte and Roberts, 2014). For the monetary policy shock, we follow Mountford and Uhlig (2008) and Rafiq and Mallick (2008) and impose only a positive reaction of the short rate itself and a negative response of inflation, leaving the uncertain response of output unrestricted.[32] As for the term premium shock, we restrict inflation to fall two to four quarters after the shock, taking into account the lags in the transmission of interest rate changes to prices and activity. Figure A5 in Annex 3 shows that the impulse response functions using these sign and zero restrictions to a free-float shock are very similar to the ones identified using our Cholesky decomposition. In particular, the slope steepens, with the long rate rising and the short rate falling after the shock. Compared to our baseline model, the rise in long rates is stronger on impact but the effect dissipates more quickly.

Table 2. Identifying sign and zero restrictions

	Output	Inflation	Short rate	Free-float	Slope	Curvature	NEER
Free-float shock	0	0		+			
Monetary policy shock		-	+				
Term premium shock		-	0		-		
(Aggregate demand shock)	+	+	+				

Notes: "0" means a zero impact of the variable on impact. "+" means a positive response of the variable after the shock and "-" a negative response.

We conclude our BVAR analysis by using our baseline Cholesky decomposition to compute the historical shock decomposition of the slope factor with a view to inspecting the role of net debt supply shocks in driving the slope in the past. In doing so, we focus on the period after the outbreak of the global financial crisis, i.e. late 2008 and early 2009, when the euro area synthetic yield curve steepened sharply (see Figure 8; cf. Figure 4). This period coincided with a marked increase in the free-float, which itself reflected a combination of an increase in new issuance of bonds and a parallel sell-off in the stock of foreign official holdings (cf. Figures 1 and 2). It is therefore the basis for a natural experiment on the role of our free-float measure in driving the euro area term structure of interest rates.

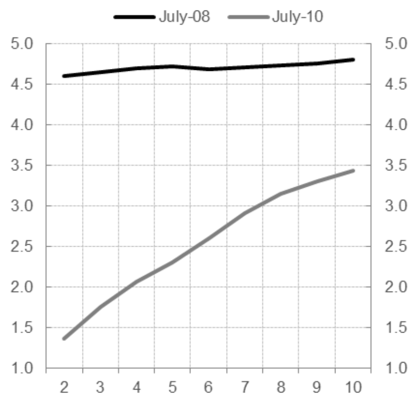
As we show in Figure 9, we find that the sharp increase in the net supply of debt after the outbreak of the global financial crisis in late 2008 contributed materially to the steepening

[31] We also test our results by identifying in addition an aggregate demand shock, which is assumed to drive output, inflation and the short rate in the same direction (see Table 2). Our results are not affected by adding this shock, but the acceptance rate drops from 17% to 8%.

[32] We find that output falls in the face of both a positive monetary policy and term premium shock, confirming conventional expectations about the effects of rising interest rates on activity.

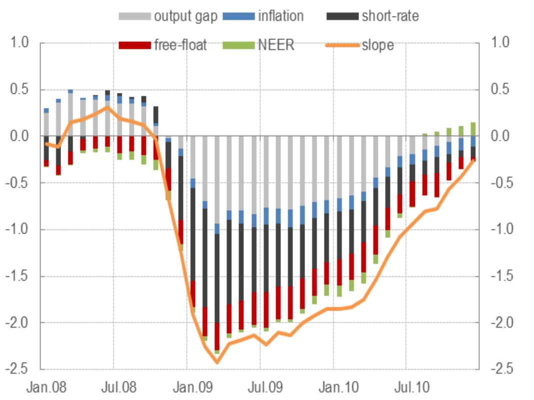
of the yield curve up until late 2010. Specifically, we estimate that the curve would have been around 20-30bps flatter in both 2009 and 2010 had it not been for the marked increase in duration risk borne by private investors. And by putting upward pressure on long-term rates, the increase in the amount of duration risk also offset the efforts by the ECB to engineer a fall in long-term rates to counter the deteriorating economic outlook. From September 2008 to May 2009, the ECB reduced the short-term rate by a cumulative 325bps, while long-term rates only fell by around 70bps – an elasticity which is much lower than in previous easing cycles.[33]

Figure 8. Euro area synthetic yield curve *(in percent; horizontal axis: maturity in years)*



Source: Author calculations.

Figure 9. Historical shock decomposition of the slope factor *(in percent)*



Notes: Derived using the Cholesky decomposition described in equation (15). For the ease of illustration, the slope excludes contributions from its own lags. We also do not show contributions from the curvature, which is, on average, marginal.

6. Simulating the impact of the ECB's PSPP

We use our model to simulate the impact of the ECB's sovereign bond purchase programme on both the euro area synthetic term structure of interest rates and the macroeconomy. In theory, there are at least two ways we could construct a counterfactual simulation. One would be to scale up the impulse response functions to be consistent with a shock to our debt supply measure that corresponds to the expected extraction of maturity-weighted bonds from euro area bond markets. Since impulse responses assume the shock occurs in the initial period, this approach would be broadly equivalent to the effect of financial markets pricing in instantly, upon announcement of the programme, the impact on the term structure. This approach has two shortcomings, however. First, as we illustrate in more

[33] For example, the ECB reduced short-term rates by a cumulative 150bps between May and November 2001. Over this period, long-term rates fell by around 60bps.

detail below, the PSPP was anticipated, and largely priced in, by the markets several months before the announcement on 22 January 2015.[34] Second, when using impulse response analysis, short-term rates are allowed to respond endogenously to the debt shock. In the case of the PSPP, the short-term would rise as output and inflation increase, thereby putting upward pressure on long-term rates in the wake of the free-float shock, which would blur the measurement of the PSPP.

For these reasons, we opt to simulate the impact of PSPP by computing out-of-sample forecasts, which condition on short-term rates and the PSPP-implied path of net debt supply. By comparing the predictions from the conditional forecast with those from an unconditional forecast, we can then gauge the likely impact of the PSPP on the term structure and the macroeconomy. We proceed in two steps. First, we compute the unconditional forecast from our model, where we impose no restrictions on the path of our free-float measure or any of the other model variables. In a second step, we condition our forecast on both (i) the unconditional forecast of the short-term rate and (ii) the unconditional forecast of the free-float, from which we subtract bond purchases under the PSPP. In doing so, we isolate the effects of ECB sovereign bond purchases from changes in the short rate and the free-float that are related to other factors. The difference between the two projections provides an estimate of the likely impact of the PSPP.

In calibrating our counterfactual scenario, we account for the markets' expectations of ECB government bond purchases. As noted above, given the difficulty in forecasting changes in outstanding duration, our estimates are based on past realisations of net debt supply. Bond purchases as a monetary policy tool are of a different nature, however. By understanding or second-guessing the reaction function of the central bank, in particular at or in proximity to the zero-lower bound for policy rates, bond purchases are often anticipated by markets well ahead of their actual implementation. Indeed, Table 3 shows the results of a monthly Bloomberg survey that asked market participants if they expected the ECB to launch a sovereign bond purchase programme. The table shows that, by December 2014 – some three months before purchases started – nearly all survey respondents were expecting the ECB to purchase government bonds. These expectations resulted in a sharp drop in market interest rates, thereby frontloading the expected easing of policy. Therefore, in conducting our counterfactual analysis, it is important to identify when news became available about changes in the net supply of debt. A failure to account for these expectations would imply that observed changes in interest rates could not be related to the APP-implied realisations in net debt supply. Hence, to draw the correct inference, we need to align our information set to that of the market. This implies that we treat the anticipation of the APP as an unexpected shock to the free-float every period.[35] From a policy perspective, this

[34] See also speech by ECB President Draghi at the ECB's Watcher Conference, 11 March 2015: https://www.ecb.europa.eu/press/key/date/2015/html/sp150311.en.html

[35] The counterfactual is run through shocks to the free-float and the policy rate.

assumption is informative under the conditions that the economy responds in the same way to unexpected and anticipated policy changes.

Table 3. Market expectations of sovereign bond purchases by the ECB

Survey date	*Share of respondents expecting purchases*	*(Expected) size*	*(Expected) maturity*
Sep-14	31.7%	500	5.45
Oct-14	52.5%	500	5.45
Nov-14	65.2%	500	5.45
Dec-14	90.6%	600	5.45
22-Jan-15	100%	850	7.43

Source: Bloomberg and author calculations. Note: Number of survey respondents varied between 44 and 55.

6.1 Calibrating the impact of PSPP on the weighted free-float

In order to calibrate the path of PSPP purchases, we use the markets' expectations about both the size of the purchase programme and the amount of extracted duration (cf. Table 3). Reports by the investment banks Nomura, JP Morgan and Morgan Stanley, issued in the spring of 2014, suggest that markets expected a total purchase volume of around €500bn initially, distributed according to the ECB's capital key, with targeted bond maturities up to 10 years, which would correspond to expectations of average weighted purchases of around 5.5 years.[36] By late December 2014, the size of the expected programme had shifted closer towards some €600bn.[37] Finally, on 22 January 2015, the ECB announced that it would purchase a combined €60bn per month of ABS, covered bonds and sovereign bonds, starting in March 2015 and running at least until September 2016.[38] The markets inferred from this information a total purchase volume of sovereign bonds over this period of around €850bn, with around €650bn being absorbed by purchases of bonds of the four largest Member States.[39] At the same time, the markets were surprised by the wide maturity spectrum of purchases, with purchases covering the 2-30 year segment, contrary to expectations of purchases being confined to the 2-10 year segment.[40]

We combine these different sources of information to construct a path for the evolution of the maturity-weighted amount of bonds that the ECB is expected to absorb from the market over the lifetime of the PSPP, starting in September 2014.[41] For the sake of simplicity, we

[36] Nomura (2014), "What would QE look like in the euro area", 17 April 2014; Morgan Stanley (2014), "What if the ECB did QE?", 12 May 2014; JP Morgan (2014), "The ECB need to do a lot more to meet its mandate (but probably won't)", 1 May 2014.

[37] Bloomberg (2015), "ECB Preview: Sovereign QE Imminent; Size, Risk-Sharing in Focus", 20 January 2015.

[38] Also subject to issue and issuer limits, see http://www.ecb.europa.eu/mopo/implement/omt/html/index.en.html.

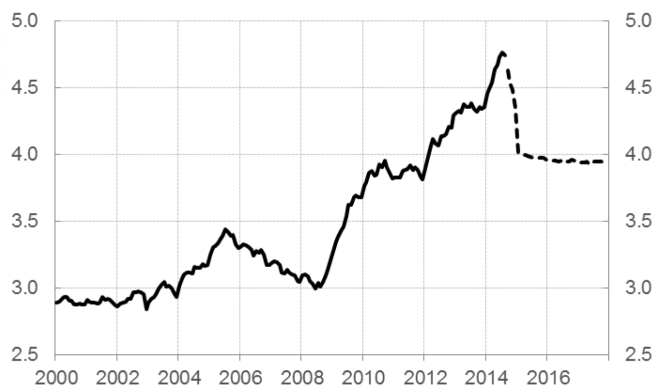
[39] See, for instance, Barclays (2015),"Quantitative (pl)easing", Euro Weekly, 26 January 2015.

[40] *Ibidem*.

[41] We focus on the APP as announced on 22 January and ignore subsequent changes to the programme as announced in December 2015 and March 2016.

assume that foreign central banks hold the composition of their portfolios constant during the implementation period.[42] This path is then subtracted from the unconditional forecast of the free-float.[43] Figure 10 shows the implied evolution of the maturity-weighted "free-float" until the end of 2017, highlighting the sharp fall in the net supply of debt arising from both the absolute size of the PSPP and the large amount of duration extracted from the market.

Figure 10. Evolution of the "free-float" under the PSPP *(as a multiple of GDP)*



Source: Author calculations. The projection of the free-float is computed by subtracting the path of sovereign bond purchases by the ECB from the unconditional model forecast of the free-float.

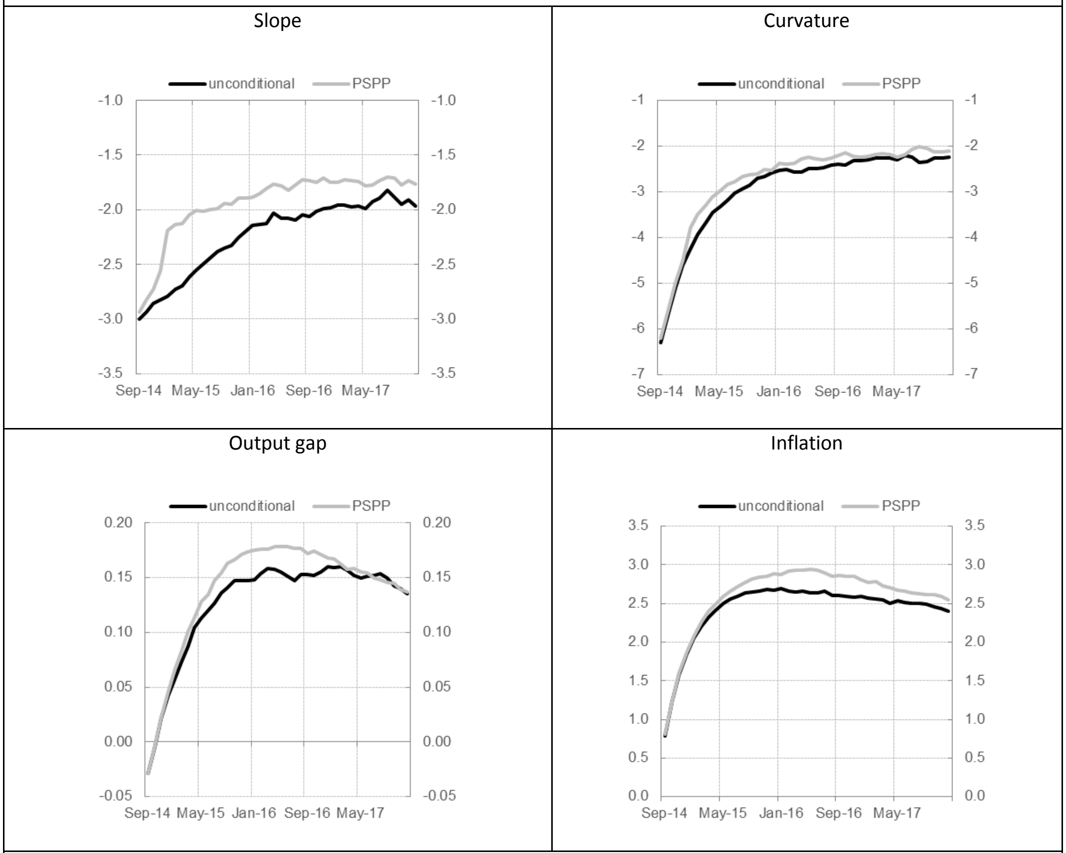
6.2 Results from the simulation analysis

The estimated median impacts of our counterfactual PSPP analysis on the yield curve and the economy are illustrated in Figure 11. The curve is predicted to flatten markedly relative to its unconditional forecast in the run-up and in the wake of the announcement of the PSPP and to remain much flatter over the entire projection horizon, converging only towards the end of 2017 (upper left-hand panel). The curve is also predicted to be somewhat less concave (upper right-hand panel). The extended period of suppressed long-term rates, in turn, translates into a steeper profile for both inflation and activity.

[42] This is not too farfetched an assumption. For one, foreign central banks are less likely to be sellers of bonds as they are to a large extent price-insensitive, driven by a mandate to keep a certain share of reserves in euro. Also, given the implied richness of bonds as a result of ECB purchases, foreign official institutions might limit their additional purchases to replace maturing bonds.

[43] Because we scale our free-float measure by nominal GDP, we first compute the unconditional forecast of nominal GDP using the projections for inflation and the output gap.

Figure 11. Conditional and unconditional out-of-sample forecasts
(in percent except for slope and curvature)



Note: Median estimates.

Table 4 quantifies the estimated impact of the PSPP. We use our Nelson Siegel state space model to convert the factor predictions into yields. As expected, the impact of the PSPP is strongest on long-term yields, with 10-year rates projected to fall, on average, by 30bps in 2015 and by 18bps and 12bps in 2016 and 2017 respectively as a result of ECB sovereign bond purchases. At the peak impact, in February 2015, 10-year yields are predicted to be 36bps lower than under the scenario of no purchases. The fact that the impact is largest at the long-end of the curve is consistent with the impact of central bank bond purchases reducing the market price of risk, through the duration channel, compressing the term spread by more at longer maturities. Given the linearity implied by the model, our estimates imply that for each €100bn of purchases, long-term rates are predicted to fall by around 6bps, or, equivalently, to fall by around 3.5bps for each percentage point of debt outstanding.[44] The output gap, meanwhile, is estimated to be some 0.2ppt higher in both 2015 and 2016, while at the peak impact in 2016 inflation is 0.3ppt higher under the PSPP.

[44] The volume of PSPP relative to the total sovereign debt market of Germany, France, Italy and Spain is equivalent to around 10% of the total outstanding market size in February 2015.

Table 4. Predicted impact of the PSPP on the term structure and economy
(yields in basis points; output gap and inflation in percentage points)

	Term structure			Output gap	Inflation
	2-year	5-year	10-year		
2015	-8	-19	-30	0.2	0.1
2016	-5	-11	-18	0.2	0.3
2017	-3	-7	-12	0.0	0.2

Source: Author calculations.

These estimates are in the ballpark of previous findings of the impact of ECB bond purchases on the yield curve. Using a controlled event study approach, Altavilla et al. (2015), for example, find that CDS-adjusted sovereign 10-year yields – which remove the credit risk component and are therefore broadly comparable in size to our estimates – fell by 17bps in Germany, 25bps in France, 33bps in Italy and 44bps in Spain.[45] Weighting these estimates by outstanding debt would imply an average fall by 29bps for the four Member States as a whole – nearly identical to the 30bps impact we find for the short-term impact. Also, although direct comparisons with estimates of the impact of asset purchases in other jurisdictions are inherently difficult, given differences in methodology as well as in the structure of financial markets and the wider economy, our results generally seem to uncover a broadly similar impact on yields and activity/inflation as documented for the US. For example, Krishnamurthy and Vissing-Jorgensen (2011) report that QE2, under which the Fed purchased $600bn worth of Treasuries, helped to reduce 10-year US Treasury rates by 18-30bps (or by 20bps using regression analysis). This implies a reduction in long-term rates of 3.5bps per percentage point of outstanding market share – similar to the findings by Li and Wei (2013) and identical to our findings for the euro area sovereign bond market.[46] D'Amico et al. (2012) find somewhat higher estimates for QE2, with long-term US Treasury rates predicted to have fallen by 45bps, i.e. an elasticity of 6.5bps per percentage point of outstanding market share. Studies on the macroeconomic impact of US QE are rarer and the range of estimates is relatively wide. For example, using a DSGE model with preferred habitat, Chen et al. (2012) show that the median GDP growth increase is 0.4% and that of inflation less than 5bps for QE2, assuming a reduction in the risk premium of 30bps. Chung et al. (2012), by contrast, find that QE1 and QE2 together boosted the level of real GDP by almost three percent and inflation by one percentage point by the second half of 2012.

[45] These estimates will also include any effects through the signalling channel. These effects, however, are likely to be less important at long maturities.

[46] Total outstanding marketable Treasury debt in November 2010, i.e. prior to the start of QE2, was $8750bn, implying purchases were equivalent to nearly 7% of the outstanding market size.

7. Conclusions

In this paper we examined how shocks to net bond supply affect the euro area synthetic term structure and macroeconomy, using the results to infer the likely impact of the ECB's PSPP.

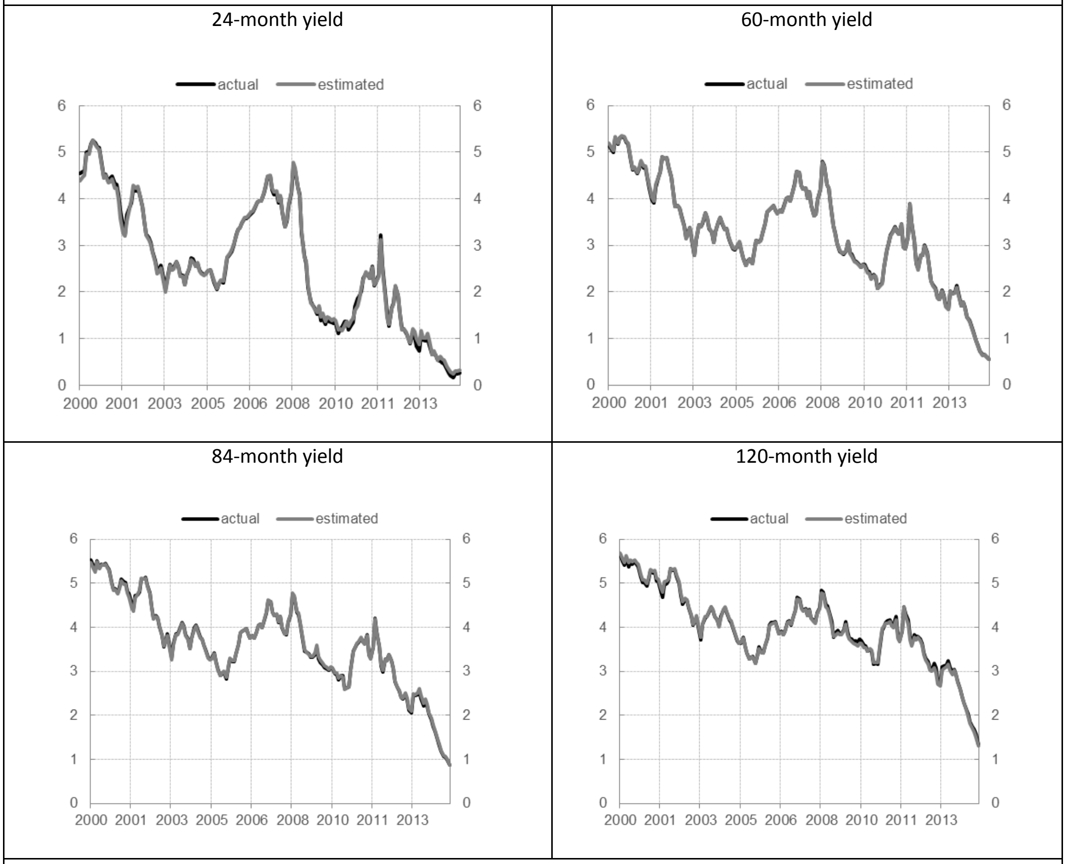
The recent literature on QE has highlighted the importance of the so-called duration channel through which central bank bond purchases, and more generally shocks to net bond supply, can affect yields. But the bulk of this literature documents the effects of asset purchase and debt structure effects for the United States and our aim was to see if the evidence supported similar channels at work in euro area sovereign bond markets. In order to do this we constructed a new measure of the bond free float, which adjusts the stock of the four largest euro area Member States' government debt outstanding for foreign official holdings of these bonds and for the maturity of the debt.

Our econometric analysis, using yield curve factors from a DNS model and a BVAR for the euro area economy, supports the existence of the duration channel in the euro area, in line with most of the recent literature on QE in other countries. Moreover, there is evidence that the impact on bond yields is transmitted via the yield curve to the broader economy, also affecting inflation. Using our model to calibrate the possible effects of the ECB's PSPP suggests that the effects could be quite substantial. According to conditional forecasts, our analysis suggests that the PSPP, as announced on 22 January 2015, could reduce 10-year yields by nearly 40bps at its peak, while the impact on inflation and the output gap in 2016 could be of the order of 0.2ppt and 0.3ppt respectively. It needs to be noted, however, that our analysis is restricted to effects from the PSPP that come through the direct (anticipated) impact of purchases on yields. Any additional effects, for example through signalling or confidence effects, are not captured by our estimates. Moreover, our analysis does not take into account the extension of the intended horizon of the APP to March 2017, announced in December 2015, or the expansion in the monthly volume of APP purchases, announced in March 2016.

Our empirical results naturally come with caveats and leave room for further work. For one, our free-float measure is only a proxy of the actual duration risk held by arbitrageurs. Future work could attempt to incorporate information on the holdings of other preferred habitat investors. Also, we restricted our analysis to realised data on the free-float in the absence of consistent high-frequency data on net bond supply expectations. One way to overcome this constraint would be to adopt a narrative-based approach similar in spirit to the Ramey (2011) analysis on fiscal shocks. On the modelling side, our results could be tested in an arbitrage-free term structure model to isolate the effects on term premia. We believe that addressing these issues would be important to improve our understanding on how net debt supply shocks propagate through both the term structure and the wider economy.

Annex 1: Estimation results from dynamic term structure model

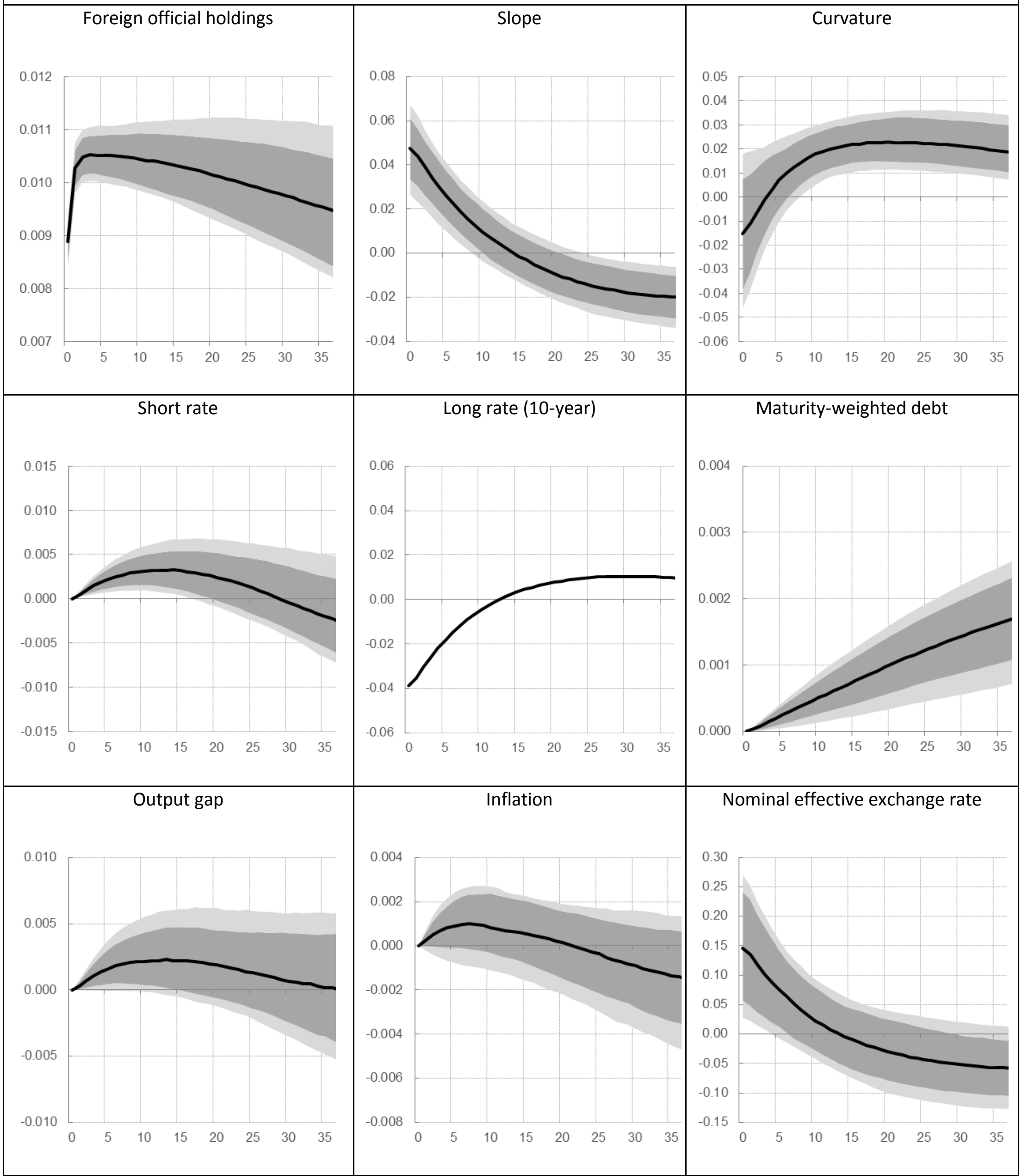
Figure A1. Actual and fitted values from state-space model
(in percent)



Note: Smoothed signal estimates from the state space model using the Kalman filter.

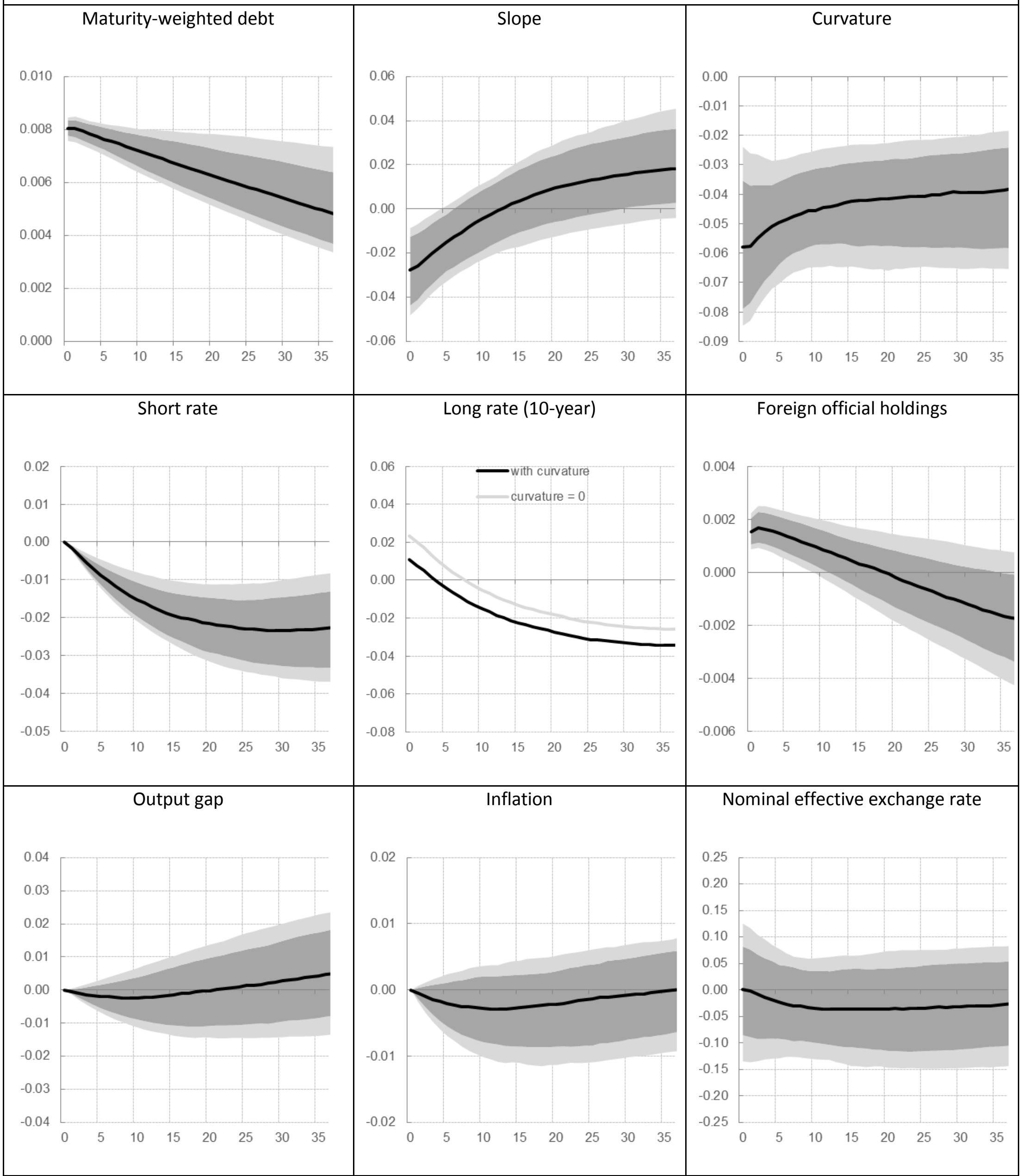
Annex 2: VAR including separately debt supply and foreign official holdings

Figure A2. Impulse response functions to a foreign official holdings shock
(one standard deviation shock)



Notes: The black solid line is the median estimate. The dark (light) grey shaded area denotes the 50th (66th) percentile confidence band. Impulse response functions for a model where the maturity-weighted debt (MWDY) and the maturity-weighted foreign official holdings (MWOHY) are included separately in the VAR (both as a share of GDP). The shocks were identified with the same Cholesky decomposition as in equation (15) where the free float was replaced with MWDY and MWOHY, where the order reflects the fact that foreign official institutions may react contemporaneously to changes in the supply of debt. The long rate has been computed by running the Nelson Siegel state space model with the impulse response functions of the factors.

Figure A3. Impulse response functions to a debt supply shock
(one standard deviation shock)

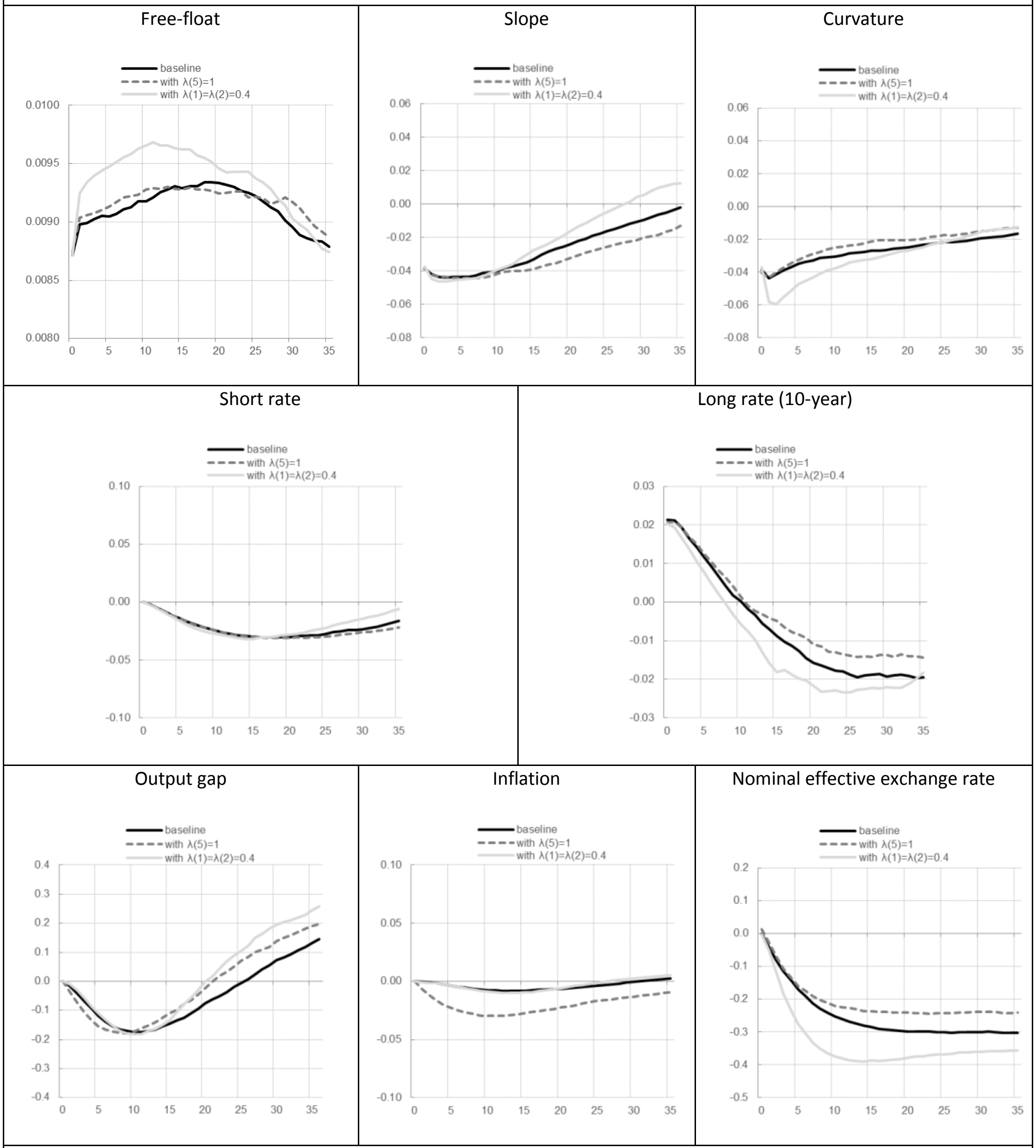


Notes: The black solid line is the median estimate. The dark (light) grey shaded area denotes the 50th (66th) percentile confidence band. Impulse response functions for a model where the maturity-weighted debt (MWDY) and the maturity-weighted foreign official holdings (MWOHY) are included separately in the VAR (both as a share of GDP). The shocks were identified with the same Cholesky decomposition as in equation (15) where the free float was replaced with MWDY and MWOHY, where the order reflects the fact that foreign official institutions may react contemporaneously to changes in the supply of debt. The long rate has been computed by running the Nelson Siegel state space model with the impulse response functions of the factors.

Annex 3: Further sensitivity analysis

Figure A4. Impulse response functions to a free-float shock

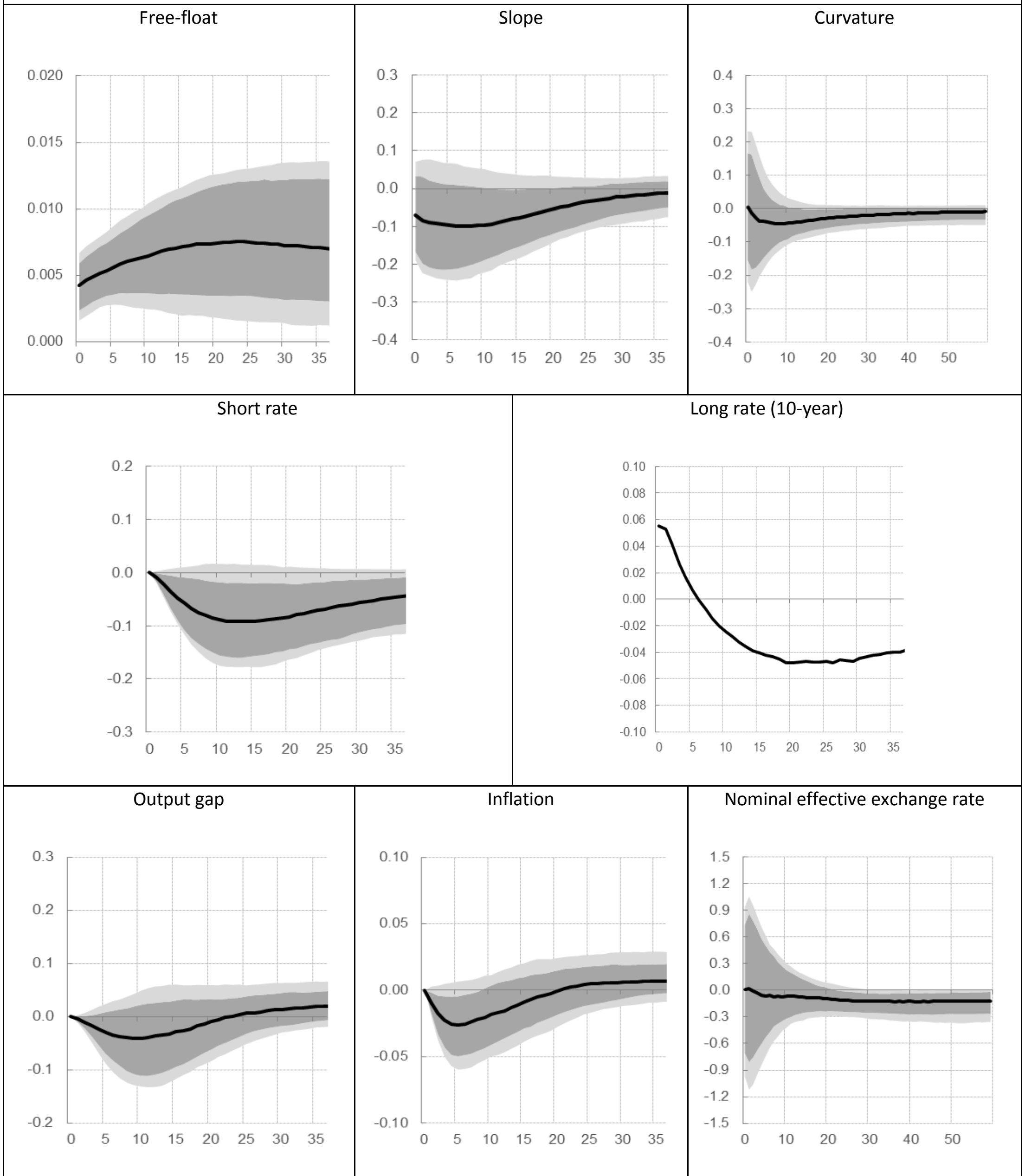
(one standard deviation shock)



Notes: Median estimates. The shocks were identified with the same Cholesky decomposition as in equation (15). The long rate has been computed by running the Nelson Siegel state space model with the impulse response functions of the factors.

Figure A5. Impulse response functions to a free-float shock using sign restrictions

(one standard deviation shock)



Notes: The black solid line is the median estimate. The dark (light) grey shaded area denotes the 50th (66th) percentile confidence band. Impulse response functions using the sign restrictions as shown in Table 2. The long rate has been computed by running the Nelson Siegel state space model with the impulse response functions of the factors.

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