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MACROECONOMIC AND MONETARY POLICY SURPRISES AND THE TERM STRUCTURE OF INTEREST RATES

by Marcello Pericoli [§]

Abstract

The no-arbitrage affine Gaussian term structure model is used to analyse the impact of macroeconomic surprises on the nominal and the real term structure in the euro area and in the United States. We find that nominal rates are affected by surprises in economic growth, the labour market and the economic outlook in the United States, and above all by surprises in inflation in the euro area. As far as real rates are concerned, we find that they are not affected by macroeconomic surprises in the United States, but they are by surprises in inflation and monetary policy in the euro area. Inflation expectations in both areas are not systematically influenced by monetary policy surprises. In the United States forward inflation risk premia became sizeable around the start of the financial crisis at the end of the last decade and increased considerably just before the adoption of the first unconventional monetary policy measures in March 2009. By contrast, in the euro area forward inflation risk premia remained unchanged even after the adoption of the unconventional monetary policy measures in October 2008 and May 2010. In both areas long-term inflation expectations have been well anchored over the past years.

JEL Classification: C02, G10, G12.
Keywords: inflation risk premium, affine term structure, Kalman filter, macroeconomic and monetary surprises.

Contents

[§] Bank of Italy, Economic Research and International Relations.

1 Introduction[1]

Over the past decade government-issued inflation-indexed, or index-linked, bonds have become available in a number of euro-area countries and have provided a fundamentally new instrument popular among institutional investors and by households, especially for retirement saving. From a policy perspective, inflation-indexed bonds can be used to extrapolate inflation expectations at different maturities. In fact, bonds linked to an inflation index differ from the corresponding standard bonds in respect of expected inflation and inflation risk premia as well as of maturities, coupon rates and cash-flow structures. In addition, as index-linked bonds have different maturities, an entire spectrum of inflation expectations and inflation risk premia can be derived from the comparison with standard nominal bonds. Hence, stemming from the no-arbitrage affine Gaussian term structure literature developed for standard bonds, some recent papers have investigated a theoretical and empirical framework to jointly price standard and index-linked bonds based on a small number of common factors. The novelty of this stream of literature, to which this paper belongs, is to have consistent, i.e. arbitrage-free, estimates of the real and nominal interest rates as well as expected inflation rates and inflation risk premia.

This paper estimates a no-arbitrage affine Gaussian term structure model for nominal and real zero-coupon interest rates implied in government bonds with macroeconomic surprises in the euro area and the United States. This class of model enables a model-implied constant-maturity inflation compensation (or model-implied breakeven inflation rate), obtained as the difference between the estimated nominal and real zero-coupon rates, to be split into the expected component (i.e. the expected inflation) and the premium requested by investors to hedge against unexpected changes in inflation, namely the inflation risk premium. This paper aims to build a bridge between models with nominal and index-linked bonds, on the one hand, and multifactor models of the term structure with observable variables à la Ang and Piazzesi (2003) and interest-rate models with macroeconomic surprises, on the other hand, by introducing the surprises inside the no-arbitrage affine Gaussian term structure framework. However, this paper does not consider macro-factors such as inflation and industrial production as it uses weekly data and, therefore focuses on information available in real time. The impact of macroeconomic surprises on the nominal and real term structure is measured by the factor loadings associated with each piece of news and their impulse response function. When the surprise of macroeconomic announcements are plugged into the term structure

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model, it is possible to estimate the impact of surprises on the entire term structure, both nominal and real, which is consistent with the absence of arbitrage in the bond markets.

A model which jointly estimates the expected inflation, the inflation risk premium and the impact of macroeconomic surprises presents three advantages with respect to the use of the plain-vanilla regression of real and nominal interest rates on surprises. First, over longer time horizons, the breakeven inflation rate can substantially differ from the expected inflation as the compensation requested by investors for uncertainty about future inflation rates – i.e. the inflation premium – can be considerable. Second, real and nominal interest rates are estimated on the basis of a common set of factors which drive the entire nominal and real term structure; so this class of model is capable of giving an economic intuition of the drivers of the nominal and real term structures. Third, this class of model gives fresh and readily available updates of market responses to surprises in inflation expectations and interest rates, key ingredients in monetary policy decisions.

This paper differs with respect to the previous macro-finance literature. First, it uses weekly data for the euro area; previous works with weekly data include those by Risa (2001) for the United Kingdom and Adrian and Wu (2010) for the United States. Second, the three latent factors are interpreted as a transformation of observable financial variables and this helps assign an economic interpretation to these factors, which drive the shape of the nominal and real term structures. Third, the same methodology is applied to the euro area and the United States, allowing a consistent comparison between the two markets. The use of weekly data is essential when this class of model is used by monetary policy makers to evaluate inflation expectations and inflation risk premia.

This paper draws on an extensive literature which establishes the significance to the bond market of various scheduled macroeconomic and monetary policy announcements. Usually bond markets are forward looking and incorporate both expected macroeconomic data and expected monetary policy interest rates; thus, only unexpected changes, e.g. surprises, can generate variations in bond market prices.

Obviously, macroeconomic and monetary policy announcements are strongly interconnected. On the one hand, changes in the interest rates across the maturity spectrum due to macroeconomic surprises can reveal information about markets' beliefs regarding the monetary policy reaction function. Usually markets expect central banks to react to surprises in the medium term and not in the short term since, as more new information accumulates, the central bank is likely to react. On the other hand, changes in the interest rates across the maturity spectrum due to monetary surprises can give a rough signal of the market's assessment of monetary policy credibility. In a credible inflation targeting regime, an increase in the policy rate is compatible with a reduction in long-term rates and a decrease in far-ahead forward inflation rates. Similarly, if far-ahead forward inflation is relatively stable and insensitive to macroeconomic surprises, then the monetary policy stance has been reasonably successful in anchoring long-term inflation expectations.

All in all, in spite of the announcements' importance, few studies examine their impact on the term structure as a whole. Most studies have looked at a single interest rate, a few rates from one part of the maturity spectrum, or a short-term rate and a long-term rate. Even when they do consider more than a single rate, there is typically no attempt to relate surprises across maturities. The aim of this paper is to help fill this gap by analyzing the reaction of nominal and real interest rates, as well as forward inflation rates, to macroeconomic and monetary policy surprises in the United States and the euro area. Moreover, the no-arbitrage affine term structure model allows for consistent comparison across the entire maturity spectrum. Lastly, the outbreak of the financial crisis in August 2007 is an event study that allows a comparison of the bond market in tranquil and turbulent times. The framework of this paper enables a comparison of both the credibility of the monetary policy stance in the two areas and the changing aspects of macroeconomic surprises.

The results show that nominal rates are impacted by macroeconomic surprises in growth, the labour market and economic outlook in the United States and by surprises in inflation in the euro area. These results may be due to differences in the mandates of the monetary authorities, which is dual in the United States and hierarchical in the euro area. Moreover, monetary policy shocks make short-term breakeven inflation rates increase in the United States, while they do not change breakeven inflation rates across the maturity spectrum in the euro area. These different responses to monetary shocks highlight dissimilarities between the markets' perception of monetary policy targets.

The paper is organized as follows. Section 2 reviews the literature on models for joint nominal and real term structures. Section 3 describes the data for the nominal and real rates and the methodology for computing the surprises. Section 4 presents the effects of surprises on interest rates. The affine Gaussian term structure model is presented in Section 5 while Section 6 presents the results. Section 7 concludes.

2 The literature

2.1 Nominal and real affine term structure models

Recent papers on the term structure of inflation can be divided into two broad groups. The first uses the standard setup of the no-arbitrage Gaussian affine term structure models of nominal and real interest rates with some identification assumptions meant to increase the power of the estimates; along this line of research there are Evans (1998), Risa (2001), Joyce et al. (2010), Ang et al. (2008), D'Amico et al. (2008), Christensen et al. (2010), Garcia and Werner (2010), Adrian and Wu (2010) and Haubrich et al. (2011, 2012). Alternatively, a second stream of work uses standard new Keynesian macrofinance models which encompass financial and macro variables; the works by

Chernov and Mueller (2012) and Hördal and Tristani (2010) belong this line of research. This paper belongs to the first category of papers.

Evans (1998) and Risa (2001) use a no-arbitrage Gaussian affine term structure model and study the term structure of real and nominal rates, expected inflation, and inflation risk premia derived from the prices of index-linked and nominal debt in the United Kingdom. Both authors find strong evidence of variable inflation risk premia throughout the term structure and, furthermore, reject both the Fisher Hypothesis and versions of the Expectations Hypothesis for real rates. In these papers the variability of the nominal to real yield spread is mostly due to inflation at the short end and to its premium at the long end.

Ang et al. (2008) develop a term structure model with regime switches, time-varying prices of risk and inflation to identify these components of the nominal yield curve. They find that the unconditional real rate curve in the United States is fairly flat around 1.3%. In one real rate regime, the real term structure is steeply downward sloping. An inflation risk premium that increases with maturity fully accounts for the generally upward sloping nominal term structure.

Christensen et al. (2010) show that the affine arbitrage-free Nelson–Siegel model can be estimated for a joint representation of nominal and real yield curves in the United States. The results suggest that long-term inflation expectations have been well anchored over the past few years in the United States and that the inflation risk premia, while volatile, have been close to zero on average. Haubrich et al. (2011, 2012) estimate the term structure of inflation expectations and inflation risk premia by means of data on inflation swap rates, nominal Treasury yields and survey forecasts of inflation. The use of inflation swap rates rules out the problems connected with the illiquidity of the index-linked Treasuries. They find that the short-term real interest rate is typically the most volatile component of the yield curve, that expected inflation over short horizons is also volatile, that investors' expectations of longer-term inflation have declined substantially over the last twenty years, and that the 10-year inflation risk premium has varied between 23 and 55 basis points. Joyce et al. (2010) and D'Amico et al. (2008) document the importance of using index-linked bonds for accurate predictions of inflation for the United Kingdom and for the United States, respectively.

Garcia and Werner (2010) document that no-arbitrage Gaussian affine term structure models fit data well in the euro area, but lack economic interpretation; so the authors introduce survey inflation risks and show that perceived asymmetries in inflation risks help interpret the dynamics of long-term inflation risk premia, even after controlling for a large number of macro and financial factors. Similarly Adrian and Wu (2010) present estimates of the term structure of inflation expectations, derived from an affine model of real and nominal yield curves for the United States. The model features stochastic covariation of inflation with the real pricing kernel. The authors fit the model not only to yields, but also to the yields' variance-covariance matrix, thus increasing the identification power, and find that model-implied inflation expectations can differ substantially from breakeven inflation rates when market volatility is high.

Within the second set of works, Chernov and Mueller (2012) use evidence from the term structure of inflation expectations to address the question of whether or not monetary policy is effective. They show that the inflation premia and out-of-sample estimates of long-term inflation suggest that U.S. monetary policy became effective over time. As an implication, their model outperforms standard macro-finance models in inflation and yield forecasting. Hördal and Tristani (2010) extend a traditional new-Keynesian macro-finance model by encompassing the nominal and the real term structure and introduce survey data on inflation and interest rate expectations at various future horizons. They show that in the euro area and in the United States, inflation risk premia are relatively small, positive, and increasing in maturity. The cyclical dynamics of long-term inflation risk premia are mostly associated with changes in output gaps, while their high-frequency fluctuations appear to be aligned with variations in inflation. However, inflation premia are countercyclical in the euro area, while they are procyclical in the United States.

2.2 Surprises and term structure models

While in the 1980s the literature focused on money supply announcements (Grossman, 1981, and Urich and Wachtel, 1981, Roley and Walsh, 1985, and Cook and Hahn, 1987), work in the 1990s documented the importance of employment, the producer price index, consumer price index, and other announcements on interest rates (Hardouvelis, 1988, and Edison, 1996). Most announcement studies, based on daily and high frequency data, document that the price response to scheduled macroeconomic announcements is typically completed within one or two minutes (Ederington and Lee, 1993, and Fleming and Remolona, 1999a and 1999b); in the U.S. bond market, the largest five minute price changes occur immediately after the release of scheduled macroeconomic announcements (Fleming and Remolona, 1997). Piazzesi (2001) estimates the effects of macroeconomic forecasts and monetary surprises on the U.S. fixed income market with daily data by means of an affine term structure model augmented with jumps. Ehrmann and Fratzscher (2005) investigate whether the degree of interdependence between the United States and the euro area has changed with EMU by analyzing the effects of surprises on daily short-term interest rates in the two economies. They find a strongly increased interdependence of money markets around EMU. Spillover effects from the United States to the euro area remain stronger than in the opposite direction, even if U.S. markets have recently started reacting to euro area developments.

In the same vein, few studies evaluate the effect of inflation targeting on long-term inflation expectations by comparing the behavior of bond yield data. Gürkaynak et. al (2010b) present an analysis on how forward interest rates and far-ahead forward inflation rates respond to unexpected monetary announcements for the United States, the United Kingdom and Sweden. If the steady-state inflation rate is constant over time and known by all agents – that is, if inflation expectations are well anchored – then standard macroeconomic models predict that inflation should return to its steady state well within ten years after a shock (Gürkaynak et al., 2005). To test whether this prediction is satisfied in the data, the analysis must look beyond the effects of economic announcements on the first few years of the term structure and focus instead on the response of far-ahead forward interest rates and inflation compensation to the announcement. Despite the novelty of these papers, the literature still lacks an analysis of announcement effects on the entire term structure.

3 The data

3.1 Nominal and real zero-coupon rates

Nominal and real zero-coupon interest rates for the euro area are estimated from end-of-week quotes of French government bonds by means of the smoothing B-spline methodology first introduced by Fisher at al. (1995) and presented in Pericoli (2013). Data range from January 2002 to April 2012. The use of French government bonds is motivated by the large number of French index-linked issues with the highest class of rating among euro-area countries; Italian index-linked government bonds have a lower rating while the few very issues of German index-linked bonds are characterized by a much shorter history.

The nominal term structure is estimated by using the quotes of the euro repo rates with maturity at 1 week, 2 weeks, 3 weeks, 1 month, 2 months, 3 months, 6 months, 9 months, 12 months for the short term, of the BTANs (*Bon à Taux Annuel Normalisé*) with maturity greater than 1 year and below 5 years, and of standard OAT (*Obligations Assimilables au Trésor*) with maturity greater than 1 year. The real term structure for the euro area is estimated using OAT€i, i.e. OAT indexed to the euro-area harmonized index of consumer prices (HICP) ex-tobacco, the reference price index of the euro area. This work considers French index-linked bonds. End-of-week mid-quotes are obtained from Bloomberg and Thomson Financial Reuters.

The nominal and real term structures for the United States are taken from the weekly data estimated by Gürkaynak et al. (2007 and 2010a).[2]

3.2 Macroeconomic and monetary surprises

Surprises are defined as an unexpected release with respect to the median forecasts released by Bloomberg. They are built in such a way that good surprises, for instance a decrease in the unemployment rate, trigger an increase in long-term yields, while negative surprises provoke a

[2] Weekly updates are available at http://www.federalreserve.gov/econresdata/researchdata.htm.

decrease. This paper uses the original estimates of the macroeconomic surprises even if most of the figures released in the euro area and in the United States are initially preliminary estimates, and are subject to review in follow-up announcements. Most of the macroeconomic datasets in empirical papers use the revised estimates for every macroeconomic figure.[3]

Let $S_{t,i}$ denote the surprise at time t in the figures indexed by i as follows:

$$S_{t,i} = \frac{R_{t,i} - F_{t,i}}{\sigma_{S_i}} \ , \tag{1}$$

where $F_{t,i}$ is the market median consensus about the upcoming figures i for t, the date of release; $R_{t,i}$ is the announcement (the first estimate) at time t of the same figure i. To make surprises comparable, they are scaled using their historical standard deviation, σ_{S_i}. This way of proceeding is very common in the literature, see for example Fleming and Remolona (1999a and 1999b) and Gürkaynak et al. (2005). The Bloomberg median survey forecasts as a measure of the market consensus for a given figure at a given date; thus, $F_{t,i}$ will be approximated by the last forecast in the Bloomberg database for each announcement.

Table 1 reports the macroeconomic surprises used in the estimates for the United States and the euro area. For both areas, surprises can be divided into four major groups; the first set of surprises encompasses data related to economic growth, the second to labour market conditions, the third to inflation and the fourth to the tone of future economic activity.

For the United States, macroeconomics are released monthly with the exception of the initial jobless claims, which has a weekly frequency, and the advanced release of the GDP rate of growth, which is quarterly. Economic growth surprises are related to the GDP rate, industrial production, the trade balance, retail sales and durable orders. Labour market indicators are nonfarm payrolls, initial jobless claims and the unemployment rate. Inflation pressure indicators are the consumer price index (CPI) and the producer price index (PPI). Finally, the two indicators of future economic activity are the ISM Manufacturing Purchasing Managers Index (the former NAPM index) and the Conference Board Consumer Confidence Index.

In the euro area all surprises have a monthly frequency except for GDP. Economic growth surprises are given by the advanced release of the GDP rate of growth, industrial production, new

[3]The Bloomberg calendar contains the Bloomberg forecasts for each of these figures, which are formed using the fiftieth empirical percentile of the distribution of a survey made of the forecasts of several bank economists, regarding a precise figure. The use of the median as a measure of the expectations makes the forecast robust to the influence of ill-intentioned economists who might want to shift the forecast in order to make the most of it. This forecast is extensively used by market participants. For each figure that is predicted by Bloomberg's collection of economists' forecasts, the median is regularly updated until every economist answers the survey, which can take up to two weeks. We retained the last median computed by the Bloomberg services, so as to match both the practitioners and academic approach.

orders, retail sales, external trade of the euro area and the current account. Signals on labour market conditions are given by the unemployment rate. Inflation indications are expressed by means of the consumer and producer price indices. Future economic activity by the Composite Purchasing Managers Index (PMI), the advanced release of the Manufacturing PMI, the Services PMI, the ZEW Survey on expectations of economic growth, and the Business Climate.

As with macroeconomic data releases, the surprise component of monetary policy announcements in each monetary area measures the effects of these announcements on interest rates. Rather than use the median of professional forecasts to measure expectations, however, this paper uses the one-week change in a short-term interest rate, such as the 30-day futures on federal funds for the United States and the 1-month Eonia swap index rate (the 1-month Overnight Index Swap from January 2002 until July 2005) for the euro area, around each monetary policy announcement to measure the surprise component of the announcement. The advantage of using market-based measures of monetary policy surprises is that they are of higher quality and are available essentially continuously (see, for example, Krueger and Kuttner, 1996; Rudebusch and Wu, 1998; Gürkaynak et al., 2007; and Gürkaynak et al., 2010a).

Obviously, there can be an interaction between monetary policy surprises and macroeconomic surprises. For example, a bad surprise about labour market conditions can influence the decision of the central bank on the stance of monetary policy.

3.2.1 The role of monetary aggregates

Among economic releases a different role is played by monetary aggregates in the United States and in the euro area. There is no question that central banks should monitor monetary developments and assess their implications for price stability thus affecting nominal and real interest rates. However, monetary aggregates have partially lost their pivotal role in both areas.

During the Volcker years once a week the financial press anticipated, tried to forecast, and then commented on the weekly releases of M2. Markets also reacted to and attempted to anticipate monetary data in the United States. Today M2 and M3 aggregates are almost completely ignored by markets. On 23 March 2006, the Federal Reserve ceased publication of the M3 monetary aggregate, along with that of large-denomination time deposits, repurchase agreements, and Eurodollars, while continuing to publish institutional money market mutual funds. According to the Federal Reserve, M3 does not appear to convey any additional information about economic activity that is not already embodied in M2 and has not played a role in the monetary policy process for many years. Consequently, the Federal Reserve judged that the costs of collecting the underlying data and publishing M3 outweigh the benefits. Nonetheless, the M2 aggregate is a large component of the Conference Board's U.S. Leading Index, making up more than 30% of the index, which contains ten indicators. In order to compare the role of monetary aggregates in the United States with that in the euro area, the surprise on U.S. M2 is computed as the weekly deviations of M2 from its exponential trend.

In contrast with the United States, the release of monetary aggregates in the euro area is highly considered as its growth rate is one of the two pillars of the area's monetary policy strategy. The monetary and economic analyses are intended to complement each other and aim to develop a deeper insight into the risks to price stability at various horizons in order to ensure that the most appropriate policy decisions are made. The European Central Bank's (ECB) two pillar strategy is one response to the difficulty of finding a single model or analytical framework which encompasses both the economic and monetary analyses in a meaningful way. Its approach is motivated by the historical evidence that money growth and inflation are closely related in the medium to long-run and is intended to ensure policy retains a medium-term focus by reducing the chances of over-reacting to the transient impacts of shocks. One element of the ECB's monetary pillar is the reference value for M3 growth. A growth rate of M3 in excess of the reference value of 4.5% per annum is, in principle, regarded as signalling a risk to inflation over the medium-term, although it does not imply a mechanical policy reaction. The ECB looks also at whether special factors such as portfolio shifts or financial innovation may be distorting the relationship.

4 The effects of surprises on interest rates

As a first step the change in nominal and real interest rates is regressed separately on macroeconomic and monetary surprises, namely

$$\Delta Y_t = \alpha + \beta \cdot S_t + v_t \ , \tag{2}$$

where Y_t is the vector of nominal and real interest rates and S is defined by (1). The results are shown in Table 2. The impact of macroeconomic surprises on the nominal term structure of the euro area is significant only for the CPI and the PMIs, the most followed indicator of future economic activity, and for monetary policy surprises. No significant impact is found for surprises in economic growth and labour market conditions. As for the United States, the impact of CPI and PMI surprises is increasing at the short end of the nominal term structure and decreasing afterwards, with the largest impact at around 4-year maturity. Conversely, the impact of a monetary surprise is decreasing along the maturity spectrum but always significant.

As regards the impact of macroeconomic surprises on the real term structure of the euro area, the results differ slightly. Macroeconomic surprises are positive and significant both for the CPI, for the short and medium term, and for the PPI, for the long term only. Business climate surprises have a negative impact on the medium-term segment of the real term structure. Finally, monetary policy surprises have a positive and significant impact on real rates, which clearly resembles that obtained for nominal rates.

The impact of macroeconomic surprises on the nominal term structure of the United States is particularly strong for retail sales, for the three labour market indicators (i.e. jobless claims, unemployment rate and nonfarm payrolls) and for the ISM index, the main future economic activity indicator. Among the inflation indicators, only the CPI affects nominal interest rates at the long end while the PPI has no effect. Monetary policy surprises impact short-term interest rates up to 4-year maturity. More interestingly, the impact of these surprises is first increasing and then decreasing showing the shape also found by Fleming and Remolona (1999) for the higher frequency. In particular, the impact of macroeconomic surprises appears greater for interest rates between 3 and 5 years of maturity. Only CPI surprises show a clear increasing trend which reaches its maximum for the 9/10-year rates. As expected, monetary policy shock impacts fade as maturities increase.

Real interest rates in the United States are much less affected by surprises than their corresponding nominal rates. Moreover, the impact seems somewhat controversial as both industrial production and the ISM indicators show a negative impact on medium-term and long-term real rates. Consumer confidence, another much followed indicator of future economic activity, also has a positive impact on long-term real rates. Finally, monetary policy surprises show a negative impact on real rates from 1 to 5-year maturity; these results, combined with those seen above for nominal rates, signal that markets change their perception on breakeven inflation rates at the shortest maturities.

All in all, the comparison between the impact of macroeconomics and monetary surprises on nominal and real rates shows that: 1) in the United States nominal rates are more affected than the corresponding euro area rates; 2) in the United States growth, labour market and future economic activity indicators have a clear and significant impact on nominal rates while in the euro area only inflation indicators and future economic activity indicators have a significant impact; 3) the factor loadings of macroeconomic surprises are hump-shaped, i.e. they increase at short maturities and decrease after the 5-year maturity; 4) monetary policy surprises have an impact on nominal rates, which is decreasing along the maturity spectrum; 5) monetary policy surprises have a negative impact on real rates in the United States and a positive impact on real rates in the euro area.

From points 2 and 5 it emerges that nominal rates are impacted by macroeconomic surprises in growth, the labour market and economic outlook in the United States and by surprises in inflation in the euro area. These results can be due to differences in the mandates of the monetary authorities, which is dual in the United States and hierarchical in the euro area. Moreover, monetary policy shocks make short-term breakeven inflation rates increase in the United States, while they do not change breakeven inflation rates across the maturity spectrum in the euro area. These differences in responses to monetary shocks also highlight the dissimilarities between the markets' perception of monetary policy targets.

5 The model

5.1 The estimation problem

This paper uses a no-arbitrage standard Gaussian affine term structure model, set in discrete time, as in the majority of the recent literature about macro term structure models. The term structures for nominal and real interest rates are linked through the pricing kernel corrected by the inflation rate (see the Appendix). This model follows the original setup by Evans (1998), successively enriched by Risa (2001), Garcia and Werner (2010), and Adrian and Wu (2010). The term structure model is expressed in the state-space form

$$\begin{aligned} Y_t &= A + HX_t + R\eta_t \quad \text{(observation equation)} \\ X_t &= \mu + \rho X_{t-1} + \Sigma\varepsilon_t \quad \text{(state equation)} \\ R &\perp \Sigma \,, \end{aligned} \tag{3}$$

where $A = [\widehat{A}_1, ..., \widehat{A}_N, A_1, ..., A_R]$ is a $(N+R) \times 1$ vector, $H = [\widehat{B}, B]^\top$ is a $(N+R) \times k$ matrix, N and R are the number of nominal and index-linked bonds used in the estimation, $\varepsilon_t \sim N(0, I_k)$, and $\eta_t \sim N(0, I_{N+R})$. The matrix Y_t contains the N nominal zero-coupon rates with annual maturity from 3 to 10 years and the R real zero-coupon rates with annual maturity from 3 to 10 years. k defines the number of latent factors in matrix X_t, namely $[l_t^1, l_t^2, \pi_t]$, which can be interpreted as two interest-rate factors and an inflation factor. For a complete formal definition see the Appendix.

The expected inflation for different horizons can be obtained from equation (3). Let $e_K = (0,0,1)^\top$ so that $e_K^\top X$ picks the latent factor related to inflation; thus the conditional expectation of inflation for τ periods ahead is given by

$$E_t(\pi_{t+\tau}) = E_t(e_K^\top X_{t+\tau}) = \tau \cdot [0 \;\; 0 \;\; 1] \cdot \left[(I-\rho)^{-1} (I - \rho^\tau)\, \mu + \rho^\tau \cdot X_t \right] \,. \tag{4}$$

The comparison between the nominal and real term structure gives the inflation compensation requested by investors to hold standard nominal bonds. This compensation, known as the breakeven inflation rate (BEIR), is equal to the difference between the nominal and real interest rates, namely $BEIR_t^n = y_t^n - r_t^n$, where y_t^n is the nominal interest rate at time t for maturity n, and r_t^n is the corresponding real interest rate. However, the BEIR is not a pure expectation of the inflation rate since, as shown by Evans (1998), it can be thought of as the sum of the expected inflation rate at time t during the n periods to maturity and the inflation risk premium at period t, γ_t^n,[4] which, using equation (4), can be written as

$$\begin{aligned}\gamma_t^n &= BEIR_t^n - E_t(\pi_{t+\tau}) \\ &= y_t^n - r_t^n - \frac{1}{\tau}E_t(e_K^\top X_{t+\tau}) \ .\end{aligned} \tag{5}$$

This premium, in a standard representative-agent power-utility model, is positive when the covariance between the stochastic discount factor and inflation is negative, in other words when expected consumption growth is low and inflation is high.

5.2 The surprises-augmented model

Model (3) can be augmented by introducing the surprises contained in the macroeconomic data releases. Thus the model becomes a state-space system with unobservable and observable variables and can be treated according to the specification of Pericoli and Taboga (2008). The augmented model is obtained by adding a new set of variables in the state equation of (3), namely

$$\begin{aligned}Y_t &= \overline{A} + \overline{HX}_t + R\eta_t \quad \text{(observation equation)} \\ \overline{X}_t &= \overline{\mu} + \overline{\rho}\overline{X}_{t-1} + \overline{\Sigma}\overline{\varepsilon}_t \quad \text{(state equation)} \\ R &\perp \Sigma \ ,\end{aligned} \tag{6}$$

with

$$\begin{aligned}\overline{A} &= \begin{bmatrix} \widehat{A}+\widehat{E} \\ A+E \end{bmatrix}, \overline{H} = \begin{bmatrix} \widehat{B} & \widehat{G} \\ B & G \end{bmatrix}, \overline{\rho} = \begin{bmatrix} \underset{k\times k}{\rho} & \underset{k\times M}{\phi} \\ \underset{M\times k}{0} & \underset{M\times M}{\rho_{uo}} \end{bmatrix}, \\ \overline{\mu} &= [\mu, \mu_S]^\top , \overline{X}_t = [X_t, S_t]^\top , \overline{\Sigma} = \begin{bmatrix} \Sigma & 0 \\ 0 & \Sigma_S \end{bmatrix} , \overline{\varepsilon}_t = [\varepsilon_t, v_t \cdot \mathfrak{I}_t] \ ,\end{aligned}$$

[4] It can be shown that if variables are jointly lognormal, this risk premium is given by $\gamma_t^n = Cov(m_t^n, \pi_t^{e,n}) - \frac{1}{2}Var(\pi_t^{e,n})$, where m_t^n is the stochastic discount factor between period t and $t+n$ and $\pi_t^{e,n}$ the expected inflation rate over the same period; in other words, the premium requested by investors to hold indexed-linked bonds and to hedge against unexpected changes in inflation depends on the covariance between the marginal rate of substitution (the stochastic discount factor) and the inflation rate; the second term is a convexity adjustment, inferred from a Jensen inequality. Sometimes, the first term of the inflation risk premium, $Cov(m_t^n, \pi_t^{e,n})$, is referred to as the 'pure inflation risk premium'.

where S_t is the row vector of matrix

$$\underset{T\times M}{S} = \begin{bmatrix} S_{1,1} & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & S_{2,t-1} & \cdots & 0 \\ S_{1,t} & 0 & \cdots & 0 \\ 0 & 0 & \cdots & S_{M,t+1} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & S_{2,T} & \cdots & 0 \end{bmatrix}.$$

Where X is the usual set of K latent factors, S is the set of M known surprises (a M-dimensional vector, $M \in \mathbb{N}$) equal to the surprise at the time of the announcement and nil otherwise. ϕ is a $M \times M$ matrix which links unobserved factors X with surprises S. Σ_S is a $M \times M$ diagonal matrix. μ_S is a $M \times 1$ vector of drifts. $\widehat{E}$ and E are the $(N+R) \times 1$ vector of drifts for the nominal and real rates in the observation equation associated with surprises S and $\widehat{G}$ and G are $(N \times M)$ and $(R \times M)$ matrices, respectively, of loadings for nominal and real rates in the observation equation associated with surprises S, $\eta_t \sim N(0, I_{N+R})$, $\varepsilon_t \sim N(0, I_K)$. $v_t \sim N(0, I_M)$ is a vector of white noise for the M announcements and $\mathfrak{I}_t$ is an indicator variable which takes value 1 when the variable S_t is different from 0 and nil otherwise. ρ_{uo} is a $(M \times M)$ diagonal matrix which describes the dynamics of the surprises S.

For ease of computation, model (6) is estimated with the monetary surprise and four macroeconomic surprises regarding growth (retail sales in the United States and in the euro area), inflation (CPI in the United States and in the euro area), the labour market (jobless claims in the United States and the unemployment rate in the euro area), and future economic activity (ISM in the United States and advanced Manufacturing PMI in the euro area); thus S becomes a $T \times 5$ matrix. The novelty of the estimates of the factor loadings $\widehat{G}$ and G is given by the fact that they are obtained through a pricing model which is arbitrage-free and thus capable of giving consistent prices across the maturity spectrum; see the Appendix for a formal definition.

Based on the state space representation in (6), the factors are filtered according to the Kalman filter. Given estimates of the latent factors $\widehat{\widehat{X}}_t$, the parameters can be estimated by maximum likelihood, based on the conditional distribution of $Y_t|Y_{t-1}$ for each observation.

6 Results

The results show that model (6) is capable of jointly estimating the nominal and real term structures for the euro area and for the United States (Table 3). Parameters' estimates are presented in Table

4. Root mean squared errors are in line with those obtained by Ang and Piazzesi (2003) for the United States while they are smaller in the euro area.

An important step towards a better understanding of the mechanics of a reduced-form no-arbitrage model like (6) consists in assigning an economic interpretation to the latent factors since it helps to provide a deeper insight into the economic forces driving bond prices. Pericoli (2012) documents that latent factors can be interpreted as the cross-sectional average of the real term structure (first factor), the slope of the real term structure computed as the difference between the 10-year and 3-year real zero-coupon rate (second factor) and the 10-year breakeven inflation rate (third factor). This last factor is a wedge between the nominal and the real interest rate. Standard three-factor models introduced by the seminal work of Litterman and Scheinkman (1991) identify the nominal term structure average, the slope of the nominal term structure and the curvature of the nominal term structure as the main driving forces of the nominal term structure. By contrast, model (6) considers two real factors (the average of the real rates and the slope of the real term structure) and an inflation factor (which summarizes the information embedded in the slope of the nominal term structure and in its curvature). Table 5 documents that the correlation between the first latent factor and the average of the real rates is large in both areas even if it decreases from September 2008 to April 2012. Moreover the correlation between the second latent factor and the slope of the real term structure is large, but becomes negative in the euro area during the crisis. Finally the correlation between the third latent factor and the breakeven inflation rate is large and increases from September 2008.

Estimates of long-term inflation expectations given by equation (4) are plotted in the top panels of Figures 1 and 2 for the United States and the euro area. In the United States the 10-year expected inflation rate records some swings at around 2 per cent from 1998 until the middle of 2004 when it starts showing steady values with much smaller variations; from the end of 2004 until the middle of 2008 the average of the 10-year expected inflation is equal to 2.2 per cent. The 10-year expected inflation rate drops in the second half of 2008 to almost nil and steadily increases in the course of 2009 up to 2 per cent. The 10-year breakeven inflation rate tracks the corresponding expected inflation quite closely until mid-2001 but records higher values afterwards. This explains why the U.S. 10-year inflation risk premium, given by the difference between the breakeven inflation and expected inflation rates, is almost nil until mid-2001 while in the following years it surges to an average of 0.40 percentage points. An alternative indication of inflation expectations comes from the expected forward inflation rate (bottom panels of Figures 1 and 2). The expected forward inflation rates, i.e. the 5-year expected inflation rate 5 years ahead, is very stable at an average of around 2.1 per cent; only in the last quarter of 2008 it declines to below 2 per cent but rapidly comes back to its long-term average. Correspondingly, the forward inflation risk premium, given by the difference between the 5-10 year breakeven forward and expected forward inflation rate, is nil on average from 1998 to mid-2001 and around 0.4 percentage points from early 2001 to mid-2005. It then drops to

0.20 percentage points, until the start of the subprime crisis in August 2007. In 2008, against the backdrop of an extremely expansive monetary stance, it increases to over 0.5 percentage points and remains above this level.

In the euro area the picture differs slightly. The 10-year expected inflation rate is steadily below the 2% monetary policy target from 2002 until 2004. It averages above 1.8 per cent from 2004 until 2008, when it drops to 1.4 per cent. From mid-2009 to the end of 2010 it is close to 1.8 per cent. By contrast to the United States, in the euro area there is a strong correspondence between the 10-year expected inflation and the 10-year breakeven rates from 2005 until 2008. Accordingly, the 10-year inflation risk premium average is very tiny in this period. The indication stemming from the expected forward rates are similar; the expected forward inflation rates, i.e. the 5-year expected inflation rate 5 years ahead, is stable at around an average of 1.8 per cent with a minor drop in the last quarter of 2008. The forward inflation risk premium, given by the difference between the 5-10 year breakeven forward and expected forward inflation rates, records wide oscillations given by the large variability of the 5-10 year breakeven forward inflation rate. However, it is on average around 50 basis points from 2005. A caveat is warranted. In actual fact, the results for the euro area for the 2002-04 period can be biased by the small number of index-linked bonds as well as by their extremely low liquidity.

6.1 Expected inflation and inflation risk premia during the crisis

The comparison between expected forward inflation rates and forward risk premia in the euro area and in the United States highlights some differences between the two areas. In the euro area, against the background of an expected forward inflation rate well anchored below 2 per cent, the forward inflation risk premium has recorded constant figures of around 0.5 percentage points. The two variables have barely changed since the adoption of unconventional monetary policy measures in the aftermath of the financial crisis. A first bold wave of unconventional monetary policy measures put forward by the ECB starts at the beginning of October 2008. A second wave, coinciding with the deterioration of the euro-area government debt markets, starts on May 2010.[5] The spot 10-year inflation risk premium does not significantly change either in October 2008 or in the second half of 2010; similarly the 5-10 year forward risk premium temporarily decreases in the second half of 2010. All in all, there is no clear effect on risk premia stemming from the unconventional measures. Note

[5] In the euro area the main unconventional measures of monetary policy are: in October 2008, the ECB introduces the "fixed-rate full allotment" that allows banks under stress to access unlimited ECB liquidity at a fixed rate in return for collateral; moreover, the ECNB expands the list of the collateral eligible for refinancing operations; in May 2009, the ECB starts outright purchases of covered bonds (Covered Bonds Purchasing Programme) in the primary and secondary market and lengthen the refinancing operations through Long-term 12-month operations; in May 2010, the ECB starts outright purchases of euro-area government bonds in the secondary market (Security Markets Programme). In December 2011 and in February 2012 the ECB introduces two 3-year refinancing operations (Longer-Term Refinancing Operations) to increase the liquidity of the banking system. See Cecioni et al. (2011) for a survey of the unconventional measures.

that the introduction of unconventional monetary policy measures in the aftermath of the financial crisis may have direct repercussion on expected inflation and on risk premia as, on the one hand, these measures tend to put pressure on expected inflation but, on the other hand, have not a clear impact on risk premia. In fact the effect on risk premia depends on the change in the covariance between the investors' stochastic discount factor and the expected inflation whose dynamics can be hardly forecastable during periods of financial stress.

Conversely, in the United States the sequence of unconventional monetary policy measures, intended to provide quantitative easing, changed the perception of expected forward inflation rates by market participants and determined a substantial and non-negligible inflation risk premium. In particular, the forward inflation risk premium shows a sudden surge first in late-2008, when speculation about the first wave of unconventional measures (the so-called Quantitative Easing 1, QE1, operative from March 2009 until February 2010) emerges, and again in early August 2010, when speculation about the second wave of measures (the so-called Quantitative Easing 2, QE2, in place since November 2010) starts to intensify. In September 2011, the Federal Reserve announces the implementation of a plan to purchase bonds with maturities of six to thirty years and to sell bonds with maturities of less than three years (Operation Twist). The aim of this plan was to do what QE has tried to do, without printing more money and without expanding the Federal Reserve's balance sheet, therefore hopefully avoiding the inflationary pressure associated with QE.

7 The effects of surprises on the term structure

From (6) it is possible to extract the factor loadings of surprises, e.g. the change in nominal and interest rates which follows a macroeconomic or monetary policy surprise. A simple back of the envelope calculation shows that changes in interest rates are obtained by subtracting Y_t from Y_{t-1} which yields

$$\begin{aligned} Y_t - Y_{t-1} &= \overline{H}\left(\overline{X}_t - \overline{X}_{t-1}\right) + R\eta_t - R\eta_{t-1} \\ &= \overline{H}\left(\overline{\rho}\overline{X}_{t-1} + \overline{\Sigma}\overline{\varepsilon}_t - \overline{X}_{t-1}\right) + R\eta_t - R\eta_{t-1} \\ &= \overline{H}(\overline{\rho} - I)\overline{X}_{t-1} + u_t \end{aligned} \tag{7}$$

where $u_t = \overline{H\Sigma}\overline{\varepsilon}_t + R\eta_t - R\eta_{t-1}$ and $\overline{H}(\overline{\rho} - I)$ are the factor loadings for the factor $\overline{X}$. The factor loading on interest rate differentials for the five surprises are given by $[0, 0, 0, 1, 1, 1, 1, 1]^\top \overline{H}(\overline{\rho} - I)$. These factor loadings obtained from model (6) correspond to those obtained from the simple unconstrained regression (2).

7.1 Monetary policy surprises

Factor loadings of monetary policy surprises are plotted in Figure 3. This model is capable of obtaining a sequence of factor loadings for nominal rates different from real rates; for the United States shocks the loadings for nominal rates are positive and decreasing while those for real rates are negative and increasing. For the euro area both sequences of factor loadings are positive but decreasing. The model is not capable of estimating the intersection of the nominal and real sequences of loadings at around 7-year maturity. Differences between constrained and unconstrained factor loadings are small for nominal rates in both areas and slightly larger for real rates, especially in the euro area.

A comparison of factor loadings before and after the collapse of Lehman Brothers, in September 2008, reveals interesting features (Table 6). In normal times, i.e. before the Lehman collapse, in the United States nominal rates reacted to monetary surprises especially at the short end of the term structure while the impact was nil on euro area nominal rates. Since the Lehman collapse nominal rates react much less in the United States and the impact is negligible on shorter-term euro-area nominal rates. Unexpectedly, monetary surprises have a positive impact on longer-term euro-area real rates. These results suggest that monetary authorities may surprise markets in normal times in the United States while the communication of the monetary policy stance is much clearer in the euro area, as bond markets are rarely surprised by the ECB.

The model can be used to extract the impulse response function from monetary surprises. Figure 4 reports the impulse of forward inflation rates between 5 and 10 years and between 9 and 10 years in the two areas. As expected, in the United States a positive monetary shock makes the forward inflation rates increase, and has the opposite effect on nominal and real rates. Conversely, in the euro area a monetary shock makes the forward inflation rates decrease. In both areas the effects of monetary surprises fade after five weeks.

7.2 Macroeconomic surprises

As a second step model (6) is estimated by combining five surprises (four macroeconomic and one monetary) in both areas. The results are consistent with those obtained in the unconstrained model (2). Figure 5 shows the cross-correlogram between macroeconomic and monetary surprises, i.e. the leads and lags between data surprises and unexpected monetary policy decisions. As expected, monetary surprises show some dependence on macroeconomic surprises; in fact, a surprise in the labour market can affect the next monetary policy move. Then a certain degree of interlinking among surprises is important in evaluating their impact on the nominal and real term structures. The cross-correlogram in both areas show that labour market surprises are followed by a surprise with the opposite sign in both areas; similarly, surprises in growth and in future economic activity are followed by a monetary surprise of the same sign. There is no clear dependence between inflation surprises and monetary policy surprises.

Like monetary surprises, the comparison between factor loadings before and after the collapse of Lehman Brothers reveals important differences between the two bond markets (Table 7). In normal times, i.e. before the Lehman collapse, in the United States nominal rates reacted to surprises in economic growth (retail sales), the economic outlook (ISM) and the labour market (jobless claims; in this case only for the shortest maturities). During the crisis the economic growth impact disappears, the labour market effect shows up with very large factor loadings, and the economic outlook effect almost doubles. In the euro area, the only relevant effect in normal times is that of inflation (CPI), which is substituted by the economic outlook impact (Manufacturing PMI) during the crisis period. The results suggest that nominal rates in the United States are driven by surprises in the real economy, both in normal and in crisis periods, but during the crisis supply-side (labour market) conditions have taken over the role played by the demand-side (retail sales) conditions; moreover, inflation never surprises nominal rates. On the contrary, in the euro area only inflation surprises impact nominal rates in normal times.

The impact on real rates is sometimes difficult to interpret. In the United States, before the Lehman collapse economic-growth and economic-outlook surprises impact real rates across the maturity spectrum; no surprise is relevant during the crisis period. In the euro area, only labour market surprises impact longer-term real rates before the Lehman collapse, while inflation scares produce a large increase in real rates after September 2008.

The impulse response function of shocks in the macroeconomic surprises shows that nominal rates react more than the corresponding real rates (Figure 6). Growth and labour market surprises have a short decay and their effects vanish after approximately six weeks. Conversely, surprises in inflation and future economic activity are much more persistent in both areas. This difference in the shocks' duration can reflect the forward nature of inflation and future economic-activity indicators with respect to growth and labour market announcements; this finding is confirmed by the dependence of monetary policy shocks and future surprises on inflation and future economic activity as demonstrated by the positive cross-correlogram of leads.

8 Number of factors and robustness checks

In order to test the performance of the three-factor model, the same model with two and four factors has been estimated. The problem of selecting the number of factors is cumbersome; Likelihood Ratio tests cannot be used to test for the number of statistically relevant factors, as some of the parameters become unidentified under the null. Previous works use three factors (D'Amico et al., 2008; Christensen et al., 2010; and Garcia and Werner, 2010), four factors (Risa, 2001) and five factors (Adrian and Wu, 2010). The criterion for using three factors in this paper is based on the cumulative explained variance of nominal and real interest rates obtained by a Principal Component Analysis. For the euro area bond market, variances explained by the first, second, third, and fourth principal factors are 88.5%, 8.4%, 2.8% and 0.2%, respectively; those for the United States market are 91.3%, 7.1%, 1.4% and 0.2%. Then, in both markets the first three factors explain more than 99.5% of the total variance and this is deemed sufficient for choosing three factors. A more thorough analysis can be made either by comparing out-of-sample errors of the pricing equations, as in Risa (2001), or by cross-validation. It appears that, in the case of two factors, the fit is not able to capture the dynamics of the term structure; in fact the unique real latent factor, which proxies the cross-sectional average of real rates, is not capable of capturing the cross-sectional dispersion among interest rates. With four factors, the model tends to overfit the term structures both for real and nominal interest rates.

The validity of estimates have also been tested by means of a number of robustness checks. First, model (6) has been enriched by introducing surveys of inflation expectations. Second, a proxy of economic growth has been introduced. This section briefly reviews the main findings of the robustness checks.

Surveys of inflation expectation are introduced in the model in order to improve its identification power, as in Chernov and Mueller (2012), D'Amico et al. (2008), Garcia and Werner (2010), and Hördal and Tristani (2010). Alternatively, Adrian and Wu (2010) use time-varying conditional covariation between real and inflation factors to increase the identification power of the model. Haubrich et al. (2011, 2012) combine the use of surveys of inflation expectation with four volatility state variables which completely determine the risk premia. A natural way to increase the identification power of the model is to use the short-term interest rate in the estimates. Model (6) is then estimated by inserting the 3-month repo interest rate in the Y matrix. The repo rate is preferred to the interbank rate and to the eurocurrency rate as it does not contain premiums for counterparty risks. The results are very similar to those presented above.

Model (6) has been estimated with each of the macroeconomic surprises available from Bloomberg for the United States, the euro area, and the three largest euro-area countries – namely Germany, France and Italy. The results show that no other macroeconomic surprises in the United States and in the euro area impact nominal and real interest rates at a weekly frequency. Only the consumer price indices of the three largest euro-area countries have an effect on the short-term segment of the nominal term structure; this effect can be explained by the relative weight of the inflation rate of each of these countries on the aggregate euro-area inflation rate. Monetary surprises in the United States have also been calculated as surprises in the expected federal funds target rate.

Finally, in the euro area surprises for the advanced GDP, the preliminary GDP, the final Manufacturing PMI, the advanced Services PMI, the advanced Composite PMI, and the advanced Consumer Confidence have been computed and used individually in model (6). In the United States the surprise for the preliminary and the final GDP have been computed and used individually in model (6). The results are substantially similar to those presented in the paper.

9 Conclusion

The paper documents the impact of surprises on the real and nominal term structure, in the euro area and the United States, in the last twelve years. The interaction between an affine Gaussian term structure model augmented with macroeconomic surprises is capable of describing, at the same time, the evolution of nominal and of real interest rates by means of a small number of latent factors and the response of real and nominal rates to surprises in economic data releases as well as to monetary surprises. The model is also capable of providing the spot long-term inflation expectation and the forward long-term inflation expectation implied in the nominal and real term structure together with the corresponding inflation risk premia. Inflation risk premia show large values and ample variability in the United States while they are smaller and more stable in the euro area.

Long-term expected forward inflation rates, a common indicator of inflation expectations, are on average below breakeven forward inflation rates in the United States, at around 2.1 per cent from 2002 until 2010; this implies that the forward inflation risk premium is on average positive in a range of 20 to 40 basis points in the United States. The forward inflation risk premia become sizable around the start of the late-2000s financial crisis and considerably increase in the United States just before the adoption of the first unconventional measures of monetary policy, known as QE1, in March 2009. In contrast, in the euro area expected forward inflation rates remain well anchored at around 1.8 per cent and the forward inflation risk premium is unchanged even after the adoption of the unconventional monetary policy measures following the peaks of the financial crisis, in October 2008 and in May 2010.

As far as macroeconomic surprises are concerned, this work contributes to this field of literature by consistently analyzing the impact of surprises on nominal and real rates. Most studies look at a single bill yield, a few yields from one part of the maturity spectrum, or a short-term yield and a long-term yield. Even when they do consider more than a single yield, there is typically no attempt to relate announcement effects across maturities. This paper innovates this strand of the literature, which still lacks an analysis for the entire yield curve.

The results show that nominal rates are impacted by macroeconomic surprises in growth, the labour market and economic outlook in the United States and by surprises in inflation in the euro area. These preliminary results can be due to the difference in the mandate of the monetary authorities, which is dual in the United States and hierarchical in the euro area. Moreover, monetary policy shocks make short-term breakeven inflation rates increase in the United States, while they do not change breakeven inflation rates across the maturity spectrum in the euro area. These different responses to monetary shocks highlight dissimilarities between the markets' perception of monetary policy targets.

Appendices

A The real term structure

The model consists of three equations. The first equation describes the dynamics of the vector of state variables X_t (a k-dimensional vector, $k \in \mathbb{N}$):

$$X_t = \mu + \rho X_{t-1} + \Sigma \varepsilon_t \ , \tag{8}$$

where $\varepsilon_t \sim N(0, I_k)$, μ is a $k \times 1$ vector and ρ and Σ are $k \times k$ matrices. Without loss of generality, it can be assumed that Σ is lower triangular. Furthermore, to ensure stationarity of the process, we assume that all the eigenvalues of ρ strictly lie inside the unit circle. The probability measure associated with the above specification of X_t will be denoted by P. X_t is a matrix containing k latent factors, which can be thought of as $k-1$ real factors and one inflation factor.

The second equation relates the one-period interest rate $r_t^1 = r_t$ to the state variables (positing that it is an affine function of the state variables):

$$r_t = -\delta_0 - \delta_1^\intercal X_t \ , \tag{9}$$

where δ_0 is a scalar and δ_1 is a $k \times 1$ vector with the last element equal to zero as the real rate is not affected by the inflation rate.

The third equation is related to bond pricing in an arbitrage-free market. A sufficient condition for the absence of arbitrage on the bond market is that there exists a risk-neutral measure Q, equivalent to P, under which the process X_t follows the dynamics:

$$X_t = \overline{\mu} + \overline{\rho} X_{t-1} + \Sigma \eta_t \ , \tag{10}$$

where $\eta_t \sim N(0, I_k)$ under Q and such that the price at time t of a bond paying a unitary amount of cash at time $t+n$ (denoted by p_t^n) equals:

$$p_t^n = \mathrm{E}_t^Q \left[\exp\left(-r_t\right) p_{t+1}^{n-1} \right] \ , \tag{11}$$

where E_t^Q denotes expectation under the probability measure Q, conditional upon the information available at time t.

The vector $\overline{\mu}$ and the matrix $\overline{\rho}$ are in general different from μ and ρ, while equivalence of P and Q guarantees that Σ is left unchanged. The link between the risk-neutral distribution Q and the physical distribution P is given by the (time-varying) price of risk which is affine in the state variables:

$$\lambda_t = \lambda_0 + \lambda_1 X_t \ ,$$

where $\lambda_0 = \Sigma^{-1}\left(\mu - \overline{\mu}\right)$ and $\lambda_1 = \Sigma^{-1}\left(\rho - \overline{\rho}\right)$. According to Cameron, Martin and Girsanov's theorem (e.g. Kallenberg - 1997)

$$\mathrm{E}_t^P \left[\frac{dQ}{dP} \right] = \prod_{j=1}^{\infty} \exp\left[-\frac{1}{2} \lambda_{t+j-1}^{\top} \lambda_{t+j-1} - \lambda_{t+j-1}^{\top} \varepsilon_{t+j} \right] \ ,$$

so that the real pricing kernel

$$m_{t+1} = \exp\left(-r_t - \frac{1}{2} \lambda_t^{\top} \lambda_t - \lambda_t^{\top} \varepsilon_{t+1} \right) \tag{12}$$

can be used to recursively price bonds:

$$p_t^n = \mathrm{E}_t^P \left[m_{t+1} p_{t+1}^{n-1} \right] \ . \tag{13}$$

Note that within this Gaussian framework, bond yields are affine functions of the state variables:

$$r_t^n = -\frac{1}{n} \ln\left(p_t^n\right) = A_n + B_n^{\intercal} X_t \ ,$$

where r_t^n is the yield at time t of a bond maturing in n periods and A_n and B_n are coefficients obeying the following simple system of Riccati equations, derived from (11)[6]:

$$\begin{aligned}
A_1 &= -\delta_0 \\
B_1 &= -\delta_1 \\
A_{n+1} &= -\delta_0 + A_n + B_n^{\intercal}(\mu - \Sigma\lambda_0) - \frac{1}{2} B_n^{\intercal} \Sigma \Sigma^{\intercal} B_n \\
B_{n+1} &= -\delta_1 + B_n^{\intercal}(\rho - \Sigma\lambda_1) \ .
\end{aligned}$$

[6] A proof by induction for a more general case can be found, for example, in Dai and Singleton (2000).

Define $A = [A_1, ..., A_{n+1}]^\intercal$ a $(n+1) \times 1$ vector and $B = [B_1, ..., B_{n+1}]^\intercal$ a $(n+1) \times k$ matrix which enter models (3) and (6).

The yields $\widetilde{r}_t^n$ and the bond prices $\widetilde{p}_t^n$ that would obtain in an arbitrage-free market populated by risk neutral investors are instead obtained setting the prices of risk to zero ($\lambda_t = 0$) in (12) and (13):

$$\widetilde{p}_t^n = \mathrm{E}_t^P \left[\exp\left(-r_t\right) \widetilde{p}_{t+1}^{n-1} \right] \ .$$

They obey the same system of recursive equations (**??**), where $\overline{\mu}$ and $\overline{\rho}$ are substituted by μ and ρ. Subtracting the risk-neutral yields $\widetilde{r}_t^n$ thus calculated from the actual yields r_t^n one obtains the term risk premia ϕ_t^n:

$$\phi_t^n = r_t^n - \widetilde{r}_t^n \ ,$$

which is the additional interest per unit of time required by investors for bearing the risk associated with the fluctuations of the price of a bond expiring in n periods. Such premia are in general time varying, and they are constant only when $\lambda_1 = 0$, i.e. for $\rho = \overline{\rho}$.

B The nominal term structure

Nominal bond prices are priced by the nominal pricing kernel $\widehat{M}$ which is linked to the real pricing kernel through the inflation rate, Π, i.e. the change in the consumer price index. Given the following relation $\widehat{M}_{t+1} = M_{t+1}/\Pi_{t+1}$, the log nominal pricing kernel is given by

$$\begin{aligned} \log \widehat{M}_{t+1} &= \widehat{m}_{t+1} = m_{t+1} - \pi_{t+1} \\ &= m_{t+1} - \exp(e_K^\top X_{t+1}) \\ &= \exp\left(-r_t - \frac{1}{2}\lambda_t^\top \lambda_t - \lambda_t^\top \varepsilon_{t+1} - e_K^\top X_{t+1} \right) \ , \end{aligned}$$

where $e_K = (0, ..., 0, 1)^\top$ and thus $e_K^\top X_{t+1}$ picks the inflation rate. Using the affine pricing rule the price of a nominal bond is given by

$$\begin{aligned} \exp\left(\widehat{A}_{n+1} + \widehat{B}_{n+1}^T X \right) &= \exp\Big[-\delta_0 + \widehat{A}_n + \left(\widehat{B}_n^\intercal - e_K^\top \right) (\mu - \Sigma\lambda_0) \\ &\quad - \frac{1}{2} \left(\widehat{B}_n^\intercal - e_K^\top \right) \Sigma\Sigma^\intercal \left(\widehat{B}_n^\intercal - e_K^\top \right)^T \\ &\quad + \left(-\delta_1 + \left(\widehat{B}_n^\intercal - e_K^\top \right) (\rho - \Sigma\lambda_1) \right) X_t \Big] \ , \end{aligned}$$

where

$$\begin{aligned}
\widehat{A}_1 &= -\delta_0 - e_K^\top \mu + \frac{1}{2} e_K^\top \Sigma\Sigma^\intercal e_K + e_K^\top \Sigma\lambda_0 \\
\widehat{B}_1 &= -\left(\delta_1 + e_K^\top \rho\right) + e_K^\top \Sigma\lambda_1 \\
\widehat{A}_{n+1} &= -\delta_0 + \widehat{A}_n + \left(\widehat{B}_n^\intercal - e_K^\top\right)(\mu - \Sigma\lambda_0) \\
&-\frac{1}{2}\left(\widehat{B}_n^\intercal - e_K^\top\right)\Sigma\Sigma^\intercal \left(\widehat{B}_n^\intercal - e_K^\top\right)^T \\
\widehat{B}_{n+1} &= -\delta_1 + \left(\widehat{B}_n^\intercal - e_K^\top\right)(\rho - \Sigma\lambda_1) \ .
\end{aligned}$$

Define $\widehat{A} = [\widehat{A}_1, ..., \widehat{A}_{n+1}]^\intercal$ a $(n+1) \times 1$ vector and $\widehat{B} = [\widehat{B}_1, ..., \widehat{B}_{n+1}]^\intercal$ a $(n+1) \times k$ matrix which enter models (3) and (6).

C The model with macroeconomic and monetary surprises

The drifts, E, and the loadings, G, for real rates associated with surprises S are defined by the usual system of Riccati equations

$$\begin{aligned}
E_1 &= -\gamma_0 \\
G_1 &= -\gamma_1 \\
E_{n+1} &= -\gamma_0 + E_n + G_n^\intercal(\mu_S - \Sigma_S\theta_0) - \frac{1}{2} G_n^\intercal \Sigma_S^\intercal \Sigma_S G_n \\
G_{n+1} &= -\gamma_1 + G_n^\intercal(\phi - \Sigma_S\theta_1) \ .
\end{aligned}$$

Define $E = [E_1, ..., E_{n+1}]^\intercal$ a $(n+1) \times 1$ vector and $G = [G_1, ..., G_{n+1}]^\intercal$ a $(n+1) \times M$ matrix which enter model (6). The equivalent equations for nominal rates have the same recursive structure, namely

$$\begin{aligned}
\widehat{E}_1 &= -\widehat{\gamma}_0 - \iota_M^\top \mu_S + \frac{1}{2} \iota_M^\top \Sigma_S \Sigma_S^\intercal \iota_M + \iota_M^\top \Sigma\theta_0 \\
\widehat{G}_1 &= -\left(\widehat{\gamma}_1 + \iota_M^\top \phi\right) + \iota_M^\top \Sigma_S\theta_1 \\
\widehat{E}_{n+1} &= -\widehat{\gamma}_0 + \widehat{E}_n + \left(\widehat{G}_n^\intercal - \iota_M^\top\right)(\mu_S - \Sigma_S\theta_0) \\
&\quad -\frac{1}{2}\left(\widehat{G}_n^\intercal - \iota_M^\top\right)\Sigma_S^\intercal \Sigma_S \left(\widehat{G}_n^\intercal - \iota_M^\top\right)^\intercal \\
\widehat{G}_{n+1} &= -\widehat{\gamma}_1 + \left(\widehat{G}_n^\intercal - \iota_M^\top\right)(\phi - \Sigma_S\theta_1) \ ,
\end{aligned}$$

where ι_M is a $(M \times 1)$ vector of parameters. Define $\widehat{E} = [\widehat{E}_1, ..., \widehat{E}_{n+1}]^\intercal$ a $(n+1) \times 1$ vector and $\widehat{G} = [\widehat{G}_1, ..., \widehat{G}_{n+1}]^\intercal$ a $(n+1) \times M$ matrix which enter model (6). Note that the equation of the real pricing kernel becomes

$$m_{t+1} = \exp\left(-r_t - \frac{1}{2}\overline{\lambda}_t^\top \overline{\lambda}_t - \overline{\lambda}_t^\top \varepsilon_{t+1}\right) , \tag{14}$$

where

$$\overline{\lambda}_t = [\lambda_0, \theta_0] + \begin{bmatrix} \lambda_1 & 0 \\ 0 & \theta_1 \end{bmatrix} \begin{bmatrix} X_t \\ S_t \end{bmatrix} .$$

D The specification of the model

The complete model (6) is defined by the following parameters

$$\begin{aligned}
\rho &= \begin{bmatrix} \rho_{11} & 0 & 0 \\ \rho_{21} & \rho_{22} & 0 \\ \rho_{31} & \rho_{32} & \rho_{33} \end{bmatrix}, \ \phi = \begin{bmatrix} \phi_{11} & \cdots & \phi_{15} \\ \vdots & \ddots & \vdots \\ \phi_{31} & \cdots & \phi_{35} \end{bmatrix}, \ \rho_{uo} = \begin{bmatrix} \rho_{uo,11} & 0 & 0 & 0 & 0 \\ 0 & \rho_{uo,22} & 0 & 0 & 0 \\ 0 & 0 & \rho_{uo,33} & 0 & 0 \\ 0 & 0 & 0 & \rho_{uo,44} & 0 \\ 0 & 0 & 0 & 0 & \rho_{uo,55} \end{bmatrix} \\
\mu &= (0, 0, \mu_\pi)^\intercal, \ \mu_S = (\mu_S^1, \mu_S^2, \mu_S^3, \mu_S^4, \mu_S^5)^\intercal \\
\delta_0 &= 0, \ \delta_1 = (\delta_1^1, \delta_1^2, 0)^\intercal, \ \gamma_0 = 0, \ \gamma_1 = (\gamma_1^1, \gamma_1^2, \gamma_1^3, \gamma_1^4, \gamma_1^5)^\intercal \\
\Sigma &= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \sigma_\pi \end{bmatrix}, \ \Sigma_S = \begin{bmatrix} \sigma_{S,11} & 0 & 0 & 0 & 0 \\ 0 & \sigma_{S,22} & 0 & 0 & 0 \\ 0 & 0 & \sigma_{S,33} & 0 & 0 \\ 0 & 0 & 0 & \sigma_{S,44} & 0 \\ 0 & 0 & 0 & 0 & \sigma_{S,55} \end{bmatrix} \\
\lambda_0 &= (\lambda_0^1, \lambda_0^2, \lambda_0^3)^\top, \ \theta_0 = (\theta_0^1, \theta_0^2, \theta_0^3, \theta_0^4, \theta_0^5)^\top = 0, \\
\lambda_1 &= \begin{bmatrix} \lambda_{1,11} & \lambda_{1,12} & \lambda_{1,13} \\ \lambda_{1,21} & \lambda_{1,22} & \lambda_{1,23} \\ \lambda_{1,31} & \lambda_{1,32} & 0 \end{bmatrix}, \ \theta_1 = \begin{bmatrix} \theta_{1,11} & 0 & 0 & 0 & 0 \\ 0 & \theta_{1,22} & 0 & 0 & 0 \\ 0 & 0 & \theta_{1,33} & 0 & 0 \\ 0 & 0 & 0 & \theta_{1,44} & 0 \\ 0 & 0 & 0 & 0 & \theta_{1,55} \end{bmatrix} \\
\sigma_N(\tau) &= c_N + d_N/\sqrt{\tau}, \text{ for } \tau = 3, ..., 10 \\
\sigma_R(\tau) &= c_R + d_R/\sqrt{\tau}, \text{ for } \tau = 3, ..., 10 \ .
\end{aligned}$$

Pericoli and Taboga (2008) show that, without loss of generality, it is possible to assume that ρ is lower triangular and that the matrix Σ is diagonal with all diagonal elements equal to one but the last. The matrix R is a 16×16 diagonal matrix whose main diagonal is given by $R = diag\,[\sigma_N(3), ..., \sigma_N(10), \sigma_R(3), ..., \sigma_R(10)]$, where $\sigma_N(\tau)$ and $\sigma_R(\tau)$ are the standard deviations of the nominal and real bond with maturity τ. Furthermore let's assume that the standard deviation of the observation errors is non increasing in the term to maturity τ, i.e. the volatility is lower for bonds with longer maturities; this notation can reflect several possible definitions of the observation error; when d_N and d_R are equal to zero the price errors are constant across maturities (Risa, 2001).

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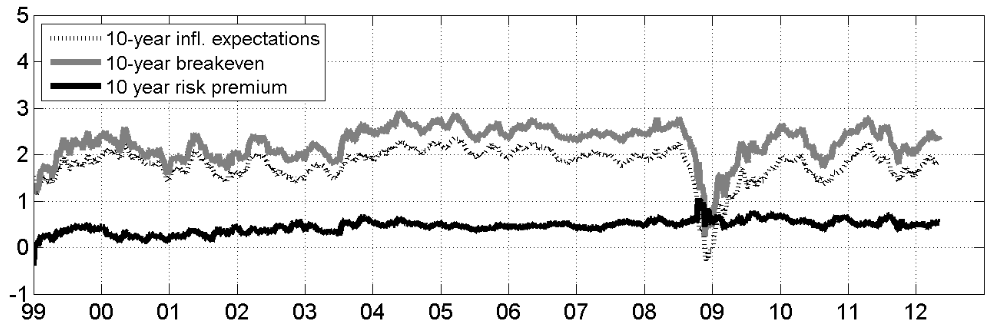
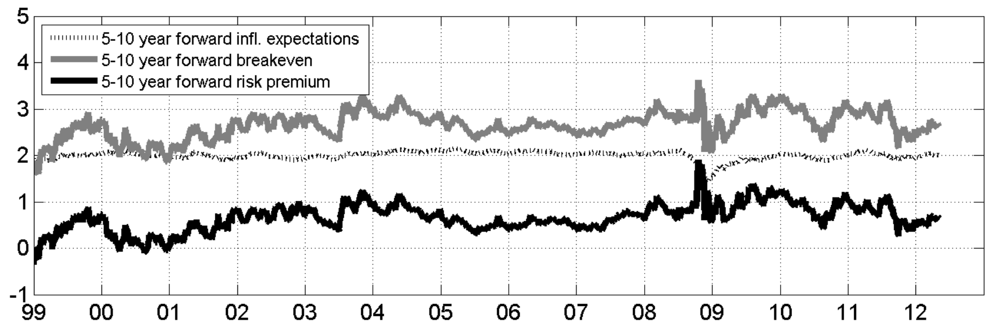
E Figures

Figure 1 – United States: breakeven inflation rates, expected inflation rates and risk premia





The 10-year expected inflation rate is given by equation (4), namely

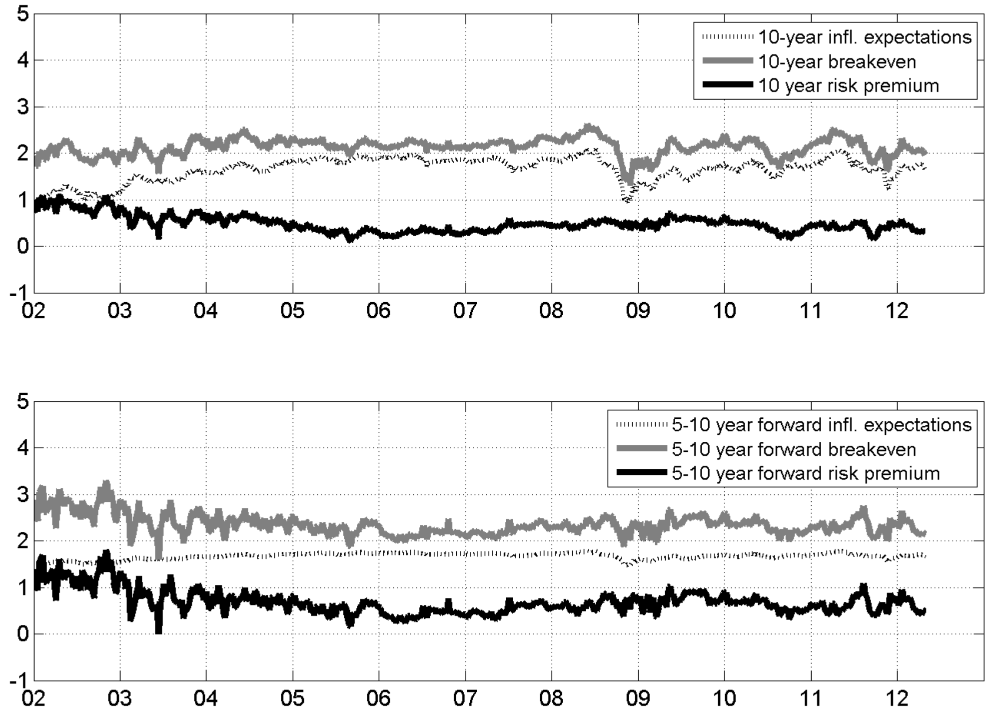
$$\frac{1}{520}E_t(e_K^\top \widehat{X}_{t+520}) = [0\ 0\ 1] \cdot \left[(I-\widehat{\rho})^{-1} \left(I - \widehat{\rho}^{520}\right) \widehat{\mu} + \widehat{\rho}^{520} \cdot \widehat{X}_t \right]$$

where 520 is the 10-year forecasting period in weeks and $\widehat{}$ above a parameter stands for its estimate. The 5-10 year expected forward inflation rate is given by

$$2 \times \frac{1}{520}E_t(e_K^\top \widehat{X}_{t+520}) - \frac{1}{260}E_t(e_K^\top \widehat{X}_{t+260})$$

where 260 is the 5-year forecasting period in weeks. The 10-year inflation risk premium is the difference between the 10-year breakeven inflation rate and (4); the 5-10 year forward risk premium is the difference between the 5-10 year breakeven forward inflation rate and the 5-10 year forward expected inflation rate.

Figure 2 – Euro area: breakeven inflation rates, expected inflation rates and risk premia



The 10-year expected inflation rate is given by equation (4), namely

$$\frac{1}{520}E_t(e_K^\top \widehat{X}_{t+520}) = [0\ 0\ 1] \cdot \left[(I - \widehat{\rho})^{-1} \left(I - \widehat{\rho}^{520}\right) \widehat{\mu} + \widehat{\rho}^{520} \cdot \widehat{X}_t\right]$$

where 520 is the 10-year forecasting period in weeks and $\widehat{}$ above a parameter stands for its estimate. The 5-10 year expected forward inflation rate is given by

$$2 \times \frac{1}{520}E_t(e_K^\top \widehat{X}_{t+520}) - \frac{1}{260}E_t(e_K^\top \widehat{X}_{t+260})$$

where 260 is the 5-year forecasting period in weeks. The 10-year inflation risk premium is the difference between the 10-year breakeven inflation rate and (4); the 5-10 year forward risk premium is the difference between the 5-10 year breakeven forward inflation rate and the 5-10 year forward expected inflation rate.

Figure 3 – Constrained and unconstrained factor loadings

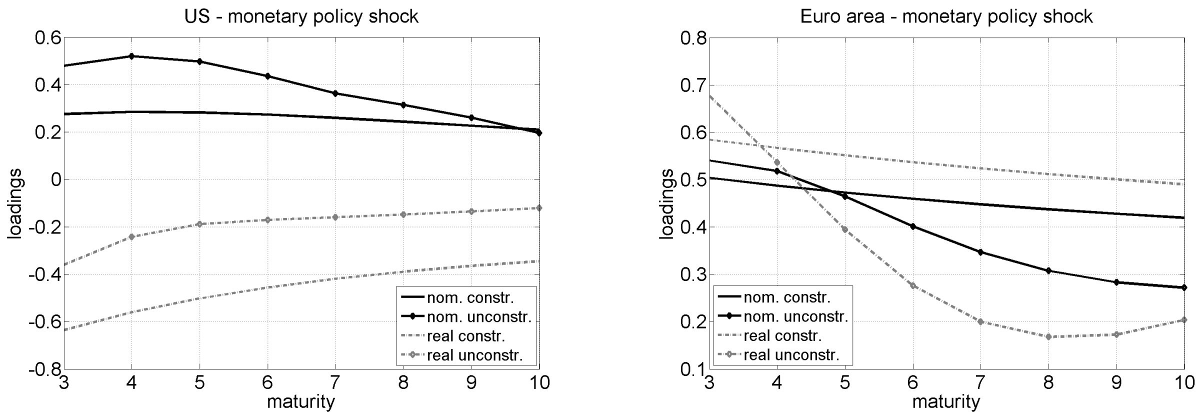
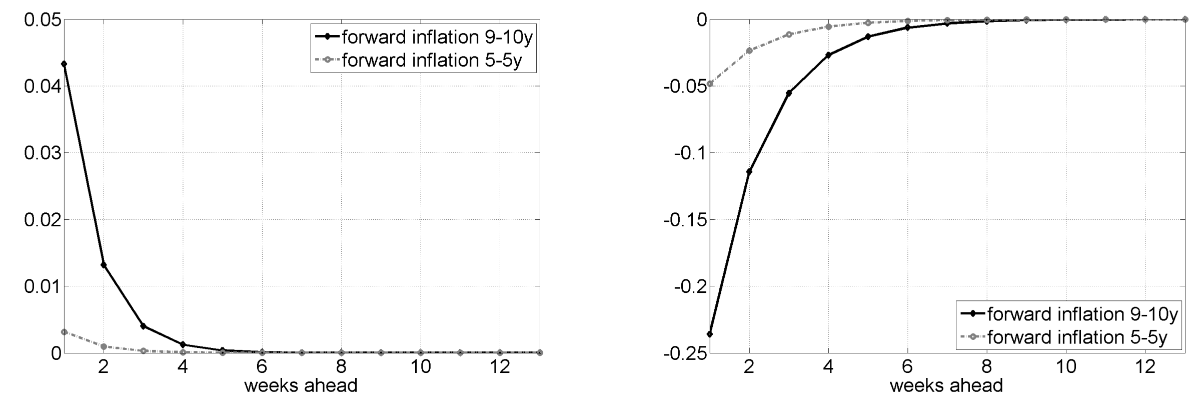
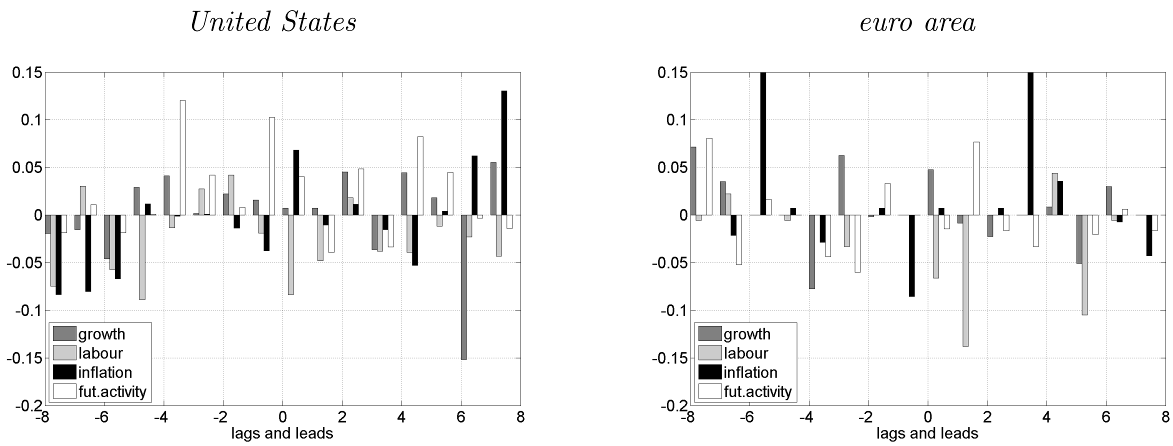


Figure 4 – Impulse response function of forward inflation rates



Note: the Figure plots the factor loadings of the unconstrained model (2) and those of the constrained model (6) given by equation (7) for nominal and real rates. Impulse response functions are obtained by (7) by one standard deviation shock of the monetary surprise.

Figure 5 – Cross-correlogram between macroeconomic and monetary news



Note: the Figure plots the cross-correlogram between the weekly news on growth, the labour market, inflation and future economic activity, on one side, and monetary policy surprises, on the other.

Figure 6a – Impulse response functions – United States

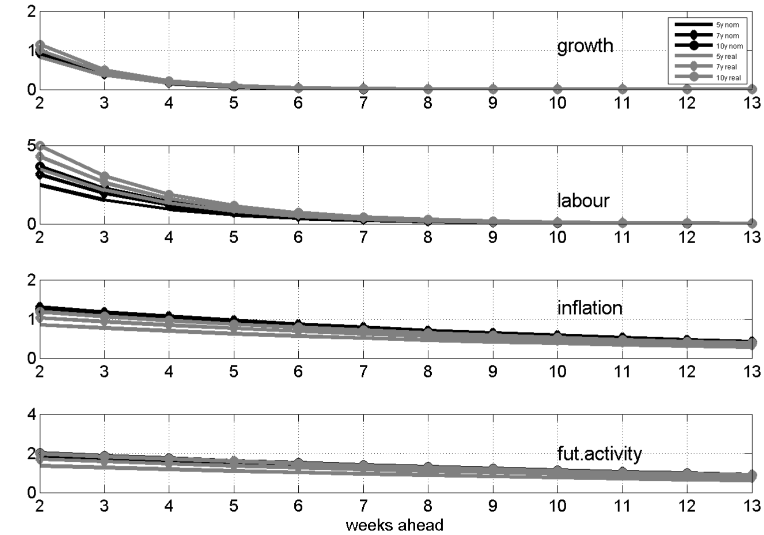
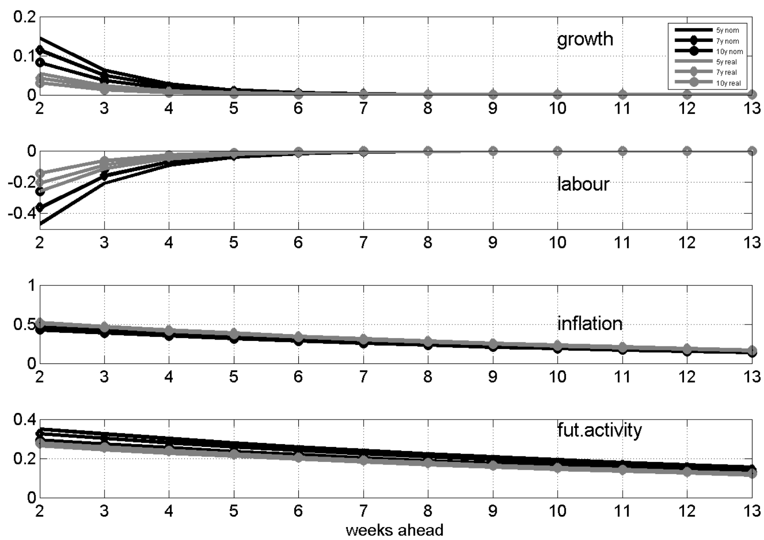


Figure 6b – Impulse response functions – euro area



Note: the Figure plots the impulse response function of the constrained model (6). given by equation (7) for nominal and real rates. Impulse response functions are obtained by (7) by one standard deviation shock of the monetary surprise. Growth refers to news on retail sales in the United States and in the euro area, inflation to news on CPI in the United States and in the euro area, the labour market to news on jobless claims in the United States and the unemployment rate in the euro area, future economic activity to ISM in the United States and PMI in the euro area.

F Tables

Table 1 – Economic variable surprises

Bloomberg code	description	freq.	mean×10^2	std	min	max	field
United States							
GDP CQOQ	GDP Chained 2005 Dollars	Q	-3.45	0.28	-4.17	2.08	growth
IP CHNG	Industrial Production	M	-10.59	0.36	-5.49	3.02	growth
USTBTOT	Trade Balance Bal. Of Payments	M	-1.48	2.96	-2.96	3.57	growth
RSTAMOM	Adj. Retail - Food Serv. Sales	M	2.1	0.7	-2.25	6.49	growth
DGNOCHNG	Durable Goods New Orders Ind.	M	-2.66	2.7	-3.03	3.99	growth
INJCJC	Initial Jobless Claims	W	26.82	21.24	-3.9	33.76	labour market
USURTOT	Unemployment Rate	M	-13.32	0.14	-3.35	2.68	labour market
NFP TCH	Employees on Nonfarm Payrolls	M	-24.73	89.61	-3.54	2.09	labour market
PPI CHNG	PPI By Proc. Stage Finish. Goods	M	6.64	0.48	-2.46	3.49	inflation
CPI CHNG	CPI Urban Consumers	M	-3.26	0.13	-2.99	2.99	inflation
NAPMPMI	ISM Manufacturing PMI SA	M	5.96	1.99	-3	3.7	future ec. act.
CONCCONF	Conference Board Cons. Conf.	M	-0.85	4.94	-2.82	2.49	future ec. act.
euro area							
EUGNEMUQ	Eurostat GDP constant prices	Q	-20.25	0.05	-5.02	1.67	growth
EUITEMUM	Eurostat Ind. Prod. ex constr.	M	-8.86	0.53	-3.35	1.86	growth
EUNOEZM	Eurostat New Orders	M	6.75	2.04	-2.78	3.32	growth
RSSAEMUM	Eurostat Retail Sales Volume	M	-24.9	0.63	-2.69	4.9	growth
XTTBEZ	Eurostat Trade Eurozone	M	2.22	5.40	-14.80	12.60	growth
EUCATLBA	Eurozone BOP CA	M	-1.45	6.71	-21.4	12.4	growth
UMRTEMU	Eurostat Unemployment rate	M	8.54	0.91	6.90	10.1	labour market
ECCPEMUM	CPI All Items	M	2.15	0.07	-4	2.66	inflation
EUPPEMUM	PPI Industry Ex constr.	M	-10.26	0.14	-6.02	2.67	inflation
GRZEEUEX	ZEW Expectation of Ec. Growth	M	1.39	7.74	-2.6	2.42	future ec. act.
PMITSEZ	Services PMI Markit Survey	M	3.73	0.56	-3.91	3.02	future ec. act.
PMITMEZ	Manufact PMI Markit Survey	M	5.08	0.3	-2.32	3.65	future ec. act.
EUBCI	EC Business Climate	M	9.61	0.19	-2.8	2.5	future ec. act.
EUCCEMU	EC Consumer Confidence	M	-8.62	1.28	-3.12	3.9	future ec. act.
EUESEMU	EC Economic Sentiment	M	4.02	1.5	-3.72	2.46	future ec. act.
ECPMICOU	EC Composite PMI Output	M	9.89	0.37	-2.66	3.19	future ec. act.
ECMA3MTH	ECB M3 Money Supply	M	0.02	0.46	-2.76	2.76	money

Source: Bloomberg. For each economic variable the surprise is computed as the difference between the actual release (Bloomberg datatype is ACTUAL_RELEASE) and the median of the survey (Bloomberg data type is BN_MEDIAN_SURVEY) and is standardized by its standard deviation. EC stands for European Commission. Q/M/W indicates that data are released at a quarterly, monthly and weekly frequency. The mean is the arithmetic average of the standardized surprise as in equation (1), std. is the standard deviation of the surprise, e.g. the denominator in equation (1), min and max are the minimum and the maximum of the standardized surprise given by equation (1). For the United States the first (advanced) release of GDP growth is used. For the euro area, the first (advanced) releases of the euro area GDP growth and the Composite PMI are used.

Table 2a – USA: impact of surprises

	nominal interest rates									
	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y
adv. GDP	0.37	1.37	1.08	0.98	0.91	0.59	0.39	0.28	0.34	0.09
Ind. prod.	0.07	0.97	0.92	0.56	0.33	0.09	-0.43	-0.67	-0.72	-1.02
BOP	-0.36	0.03	0.68	1.05	1.21	1.43	1.47	1.61	1.73	*1.77*
Retail	**3.77**	**5.11**	**5.30**	**5.35**	**5.49**	**5.48**	**5.25**	**5.11**	**4.97**	**4.67**
Dur. goods	0.45	1.05	1.11	1.17	1.20	1.16	1.13	1.08	1.04	0.95
Job. claims	**-2.27**	**-2.40**	**-2.66**	**-2.63**	**-2.26**	**-2.27**	**-2.29**	**-2.21**	**-2.22**	**-2.33**
Unemp.	*-1.35*	**-2.15**	**-2.51**	**-2.56**	**-2.48**	**-2.45**	**-2.49**	**-2.41**	**-2.54**	**-2.67**
NF payroll.	**4.07**	**5.63**	**5.63**	**5.61**	**5.68**	**5.40**	**5.10**	**4.55**	**4.24**	**4.21**
CPI	0.67	0.94	1.18	1.42	1.62	*1.82*	*1.98*	**2.21**	**2.52**	**2.58**
PPI	1.45	1.45	1.61	1.62	1.63	1.73	*1.77*	*1.91*	**2.13**	**2.27**
ISM	**3.29**	**4.46**	**4.68**	**4.70**	**4.82**	**4.71**	**4.47**	**4.35**	**4.20**	**3.83**
Cons. conf.	0.46	0.31	0.44	0.34	0.21	0.17	-0.04	-0.09	0.10	0.40
M2	0.27	0.42	*0.48*	0.52	0.50	0.44	0.36	0.31	0.26	0.20
Mon. pol.	**0.70**	**0.51**	**0.47**	**0.42**	**0.34**	*0.27*	0.21	0.19	0.19	0.16

	real interest rates									
	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y
	1	2	3	4	5	6	7	8	9	10
adv. GDP	-14.95	-6.20	-2.48	-1.03	-0.54	-0.46	-0.56	-0.71	-0.87	-1.02
Ind. prod.	*-7.07*	-4.72	-1.49	0.11	0.67	0.81	0.83	0.81	0.80	0.79
BOP	0.34	0.12	0.29	0.54	0.73	0.95	1.12	1.27	*1.39*	*1.49*
Retail	-2.40	0.85	2.23	**2.77**	**2.81**	**2.81**	**2.74**	**2.66**	**2.58**	**2.52**
Dur. goods	-3.46	-1.48	-0.07	0.70	1.10	1.28	1.32	1.28	1.20	1.09
Job. claims	0.70	-1.86	**-2.05**	**-1.92**	**-1.73**	**-1.59**	*-1.47*	*-1.36*	*-1.26*	*-1.17*
Unemp.	*-7.13*	-2.69	-1.12	-0.69	-0.60	-0.68	-0.77	-0.83	-0.87	-0.88
NF payroll	-1.93	1.83	**3.59**	**4.22**	**4.27**	**4.15**	**3.96**	**3.77**	**3.60**	**3.46**
CPI	-0.51	-0.81	-0.56	-0.34	-0.10	0.13	0.34	0.50	0.62	0.70
PPI	-1.93	-2.09	-1.88	-1.56	-0.98	-0.73	-0.53	-0.39	-0.30	-0.23
ISM	0.16	2.17	**2.59**	**2.53**	**2.38**	**2.26**	**2.20**	**2.17**	**2.17**	**2.17**
Cons. conf.	**9.69**	**4.83**	*2.20*	0.71	-0.11	-0.54	-0.76	-0.87	-0.91	-0.93
M2	-1.28	-0.64	-0.36	-0.24	-0.19	-0.17	-0.16	-0.15	-0.14	-0.12
Mon. pol.	0.17	0.19	0.12	0.03	-0.03	-0.05	-0.05	-0.05	-0.05	-0.05

The table shows the estimates of the βs in the multivariate regression (2); in bold (italics) the coeffcents significant at the 95 (90) per cent significance level. Standard errors are computed using 5 Newey-West lags for correcting autocorrelation and heteroskedasticity. Surprises for M2 are computed as deviations of the weekly monetary aggregate M2 from its exponential trend.

Table 2b – Euro area: impact of surprises

	nominal interest rates									
	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y
adv. GDP	1.20	0.91	0.61	0.29	-0.05	-0.37	-0.65	-0.88	-1.05	-1.18
Ind. prod.	**2.47**	**2.41**	**2.35**	**2.33**	**2.35**	**2.35**	**2.28**	**2.15**	**1.96**	**1.74**
New. orders	-0.44	-0.58	-0.67	-0.72	-0.75	-0.75	-0.69	-0.59	-0.45	-0.27
Ret. sales	1.12	0.88	0.67	0.48	0.30	0.15	0.04	-0.02	-0.04	-0.04
Trade	-1.18	-1.29	-1.33	-1.33	-1.32	-1.30	-1.25	-1.18	-1.11	-1.04
BOP	0.90	0.76	0.62	0.47	0.33	0.22	0.14	0.10	0.08	0.07
Unemp.	**-40.39**	**-37.60**	**-34.87**	**-33.31**	**-32.95**	**-32.67**	**-31.65**	**-29.73**	**-27.12**	*-24.19*
CPI	*3.17*	**3.15**	**3.14**	**3.03**	**2.80**	*2.53*	*2.27*	*2.06*	1.89	1.76
PPI	**3.04**	**2.41**	*1.83*	1.39	1.11	0.92	0.78	0.67	0.58	0.49
ZEW	*2.77*	*2.44*	2.05	1.71	1.48	1.34	1.26	1.23	1.22	1.24
adv. Man. PMI	**3.55**	**3.73**	**3.89**	**3.93**	**3.83**	**3.65**	**3.44**	**3.23**	**3.04**	**2.91**
Serv. PMI	0.60	1.21	1.73	2.15	*2.49*	**2.73**	**2.88**	**2.95**	**2.96**	**2.93**
Comp. PMI	3.63	**4.12**	**4.57**	**4.93**	**5.18**	**5.31**	**5.31**	**5.22**	**5.07**	**4.91**
Bus. clim.	*2.34*	*2.18*	*1.98*	1.69	1.32	0.97	0.67	0.47	0.34	0.28
Cons. conf.	*2.26*	*1.96*	1.65	1.32	0.97	0.64	0.33	0.05	-0.20	-0.43
Ec. sent.	*2.42*	*1.93*	1.44	0.99	0.59	0.25	-0.02	-0.25	-0.43	-0.60
M3	*0.02*	**0.03**	**0.03**	**0.03**	**0.02**	0.02	0.02	0.02	0.01	0.01
Mon. pol.	0.02	0.04	0.07	0.09	*0.11*	**0.13**	**0.14**	**0.14**	**0.14**	**0.14**

	real interest rates									
	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y
adv. GDP	0.51	0.34	0.20	0.12	0.08	0.06	0.05	0.02	-0.03	-0.08
Ind. prod.	2.58	2.56	*2.53*	**2.48**	**2.40**	**2.26**	**2.04**	*1.76*	1.45	1.15
New orders	-2.30	-2.02	-1.78	-1.64	-1.57	-1.46	-1.23	-0.87	-0.43	0.04
Ret. sales	1.82	1.59	1.36	1.11	0.87	0.66	0.50	0.41	0.36	0.34
Trade	-0.68	-0.79	-0.89	-0.97	-1.01	-1.01	-0.97	-0.90	-0.81	-0.72
BOP	0.96	0.92	0.91	0.94	1.01	1.04	1.01	0.89	0.71	0.47
Unemp.	*-56.64*	*-47.17*	*-38.43*	*-31.25*	-25.84	-21.77	-18.63	-16.20	-14.38	-13.12
CPI	**6.23**	**5.72**	**5.17**	**4.58**	**3.95**	**3.36**	**2.86**	**2.46**	*2.14*	1.91
PPI	2.71	*2.68*	*2.64*	**2.60**	**2.56**	**2.50**	**2.43**	**2.33**	**2.22**	**2.11**
ZEW	-0.13	0.04	0.19	0.32	0.43	0.53	0.60	0.66	0.70	0.73
adv. Man. PMI	2.12	2.61	2.99	*3.22*	**3.31**	**3.30**	**3.23**	**3.12**	**2.98**	**2.84**
Serv. PMI	1.15	1.23	1.31	1.37	1.42	1.47	1.51	1.56	1.61	1.66
Comp. PMI	0.84	0.88	0.90	0.88	0.83	0.73	0.61	0.47	0.33	0.21
Bus. clim.	-1.98	-2.05	-2.08	-2.02	-1.86	-1.68	-1.52	-1.40	-1.32	-1.28
Cons. conf.	1.78	1.22	0.76	0.46	0.33	0.23	0.08	-0.13	-0.40	-0.69
Ec. sent.	-0.44	-0.74	-0.98	-1.10	-1.13	-1.15	-1.23	-1.37	*-1.57*	**-1.80**
M3	**0.05**	**0.04**	**0.03**	**0.03**	*0.02*	0.01	0.01	0.01	0.01	0.01
Mon. pol.	16.90	*17.57*	**18.20**	**18.72**	**19.13**	**19.47**	**19.77**	**20.03**	**20.22**	**20.31**

The table shows the estimates of the βs in the multivariate regression (2); in bold (italics) the coefficients significant at the 95 (90) per cent significance level. Standard errors are computed using 5 Newey-West lags for correcting autocorrelation and heteroskedasticity. The first releases (advanced) of GDP growth and Manufactuirng PMI are used.

Table 3a – United States: yield pricing errors in basis points

	nominal			real		
	mean	RMSE	std.dev.	mean	RMSE	std.dev.
3-yr	10.48	26.76	24.64	0.24	15.37	15.38
4-yr	-0.12	21.49	21.50	0.63	14.86	14.86
5-yr	-3.82	20.62	20.28	1.46	15.34	15.28
6-yr	-4.02	20.01	19.62	2.00	15.28	15.16
7-yr	-2.49	19.84	19.70	2.10	15.08	14.94
8-yr	-0.28	20.36	20.37	1.78	15.00	14.90
9-yr	2.02	21.46	21.38	1.10	15.17	15.14
10-yr	4.02	22.85	22.51	0.13	15.65	15.66

Note: statistics of weekly data from January 2002 to April 2012. Pricing error is defined as the percentage point difference $\times 100$ between the current and the estimated yield. RMSE is the root mean squared error of the error in basis points; std.dev. is the standard deviation of the error in basis points.

Table 3b – Euro area: yield pricing errors in basis points

	nominal			real		
	mean	RMSE	std.dev.	mean	RMSE	std.dev.
3-yr	1.38	14.65	14.60	-0.12	18.30	18.31
4-yr	1.04	15.34	15.32	-0.85	16.05	16.05
5-yr	1.36	16.37	16.33	-0.54	14.82	14.82
6-yr	1.81	17.27	17.19	0.14	14.29	14.30
7-yr	2.11	17.96	17.85	0.75	14.17	14.17
8-yr	2.17	18.44	18.33	1.12	14.26	14.23
9-yr	1.99	18.85	18.76	1.22	14.54	14.50
10-yr	1.65	19.32	19.27	1.09	15.09	15.06

Note: statistics of weekly data from January 2002 to April 2012. Pricing error is defined as the percentage point difference $\times 100$ between the current and the estimated yield. RMSE is the root mean squared error of the error in basis points; std.dev. is the standard deviation of the error in basis points.

Table 4 – Parameter estimates

US	coefficient	std.err.	euro area	coefficient	std.err.
ρ_{11}	0.998	0.304	ρ_{11}	0.989	0.134
ρ_{21}	-0.004	0.151	ρ_{21}	-0.001	0.340
ρ_{22}	0.999	0.027	ρ_{22}	0.996	1.064
ρ_{31}	-0.000	0.086	ρ_{31}	0.008	0.028
ρ_{32}	-0.000	0.013	ρ_{32}	-0.007	0.061
ρ_{33}	0.993	0.008	ρ_{33}	0.989	0.005
μ_π	0.030	48.341	μ_π	0.060	39.359
σ_π	-0.268	0.494	σ_π	-0.114	0.086
δ_0	-40.895	5.439	δ_0	-72.063	48.945
$\delta_{1,1}$	0.246	216.415	$\delta_{1,1}$	0.133	0.744
$\delta_{1,2}$	-66.370	56.304	$\delta_{1,2}$	-122.733	312.417
$\delta_{1,3}$	12.352	0.000	$\delta_{1,3}$	-18.485	0.000
$\lambda_{0,1}$	0.016	4.205	$\lambda_{0,1}$	-0.025	3.918
$\lambda_{0,2}$	1.372	1.181	$\lambda_{0,2}$	1.173	1.320
$\lambda_{0,3}$	0.023	13.151	$\lambda_{0,3}$	0.008	40.025
$\lambda_{1,11}$	0.006	0.307	$\lambda_{1,11}$	-0.008	0.134
$\lambda_{1,12}$	1.996	0.026	$\lambda_{1,22}$	1.940	2.374
$\lambda_{1,13}$	6.930	0.000	$\lambda_{1,33}$	172.666	0.000
$\lambda_{1,21}$	0.284	0.298	$\lambda_{1,12}$	-0.005	0.005
$\lambda_{1,22}$	-0.000	3.890	$\lambda_{1,21}$	-0.161	6.228
$\lambda_{1,23}$	-0.002	16.362	$\lambda_{1,13}$	-0.000	0.002
$\lambda_{1,31}$	0.091	0.025	$\lambda_{1,23}$	0.042	0.680
$\lambda_{1,32}$	0.003	6.492	$\lambda_{1,31}$	-1.424	6.602
$\lambda_{1,33}$	-0.006	6.087	$\lambda_{1,32}$	-0.021	4.867
c_N	0.001	0.075	c_N	0.089	0.151
d_N	0.023	1.124	c_R	-0.010	0.645
c_R	-0.015	1.192	d_N	-0.046	0.118
d_R	-0.005	1.035	d_R	0.049	0.053

Note: the table reports the estimates of model (3) for the euro area and for the United States. Parameters for the surprises are not reported. Standard errors are computed with the outer product.

Table 5 – Correlation of latent factors with observable variables

United States	Jan '98 - Apr '12	Jan '98 - Sep '08	Oct '98 - Apr '12
1st factor - average real rates	0.78	0.68	0.67
2nd factor - slope of real rates	0.47	0.64	0.40
3rd factor - BEIR	0.93	0.92	0.98
Euro area	Jan '02 - Apr '12	Jan '02 - Sep '08	Oct '98 - Apr '12
1st factor - average real rates	0.95	0.94	0.84
2nd factor - slope of real rates	0.53	0.49	-0.16
3rd factor - BEIR	0.72	0.73	0.77

The Table reports the absolute value of the correlation between the three latent factors, defined in the column as 1st, 2nd and 3rd, and the observable variables, defined as the average of real rates, the slope of real rates – the difference between the 10-year and the 3-year real rate – and the 10-year BEIR.

Table 6 – Monetary surprises on nominal and real rates before and after the Lehman collapse

United States	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
nominal rates										
full sample	**0.70**	**0.51**	**0.47**	**0.42**	**0.34**	0.27	0.21	0.19	0.19	0.16
pre-Lehman	**0.67**	**0.45**	**0.41**	**0.38**	**0.32**	**0.31**	**0.32**	**0.30**	0.26	0.24
post-Lehman	**0.77**	**0.71**	**0.66**	**0.55**	0.39	0.11	-0.20	-0.21	-0.06	-0.09
real rates										
full sample	0.17	0.19	0.12	0.03	-0.03	-0.05	-0.05	-0.05	-0.05	-0.05
pre-Lehman	-0.03	0.24	0.27	**0.25**	0.23	0.20	0.19	0.17	0.16	0.15
post-Lehman	0.82	0.00	-0.40	-0.75	-0.90	-0.92	-0.89	-0.84	-0.79	-0.75

euro area	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
nominal rates										
full sample	0.02	0.04	0.07	0.09	0.11	0.13	**0.14**	**0.14**	**0.14**	**0.14**
pre-Lehman	0.16	0.17	0.18	0.18	0.17	0.16	0.16	0.16	0.17	**0.18**
post-Lehman	-0.03	0.00	0.04	0.07	0.10	0.12	0.13	0.14	0.13	0.13
real rates										
full sample	0.17	0.18	**0.18**	**0.19**	**0.19**	**0.19**	**0.20**	**0.20**	**0.20**	**0.20**
pre-Lehman	0.37	0.33	0.28	0.24	0.20	0.17	0.14	0.12	0.11	0.11
post-Lehman	0.10	0.13	0.15	0.17	**0.19**	**0.21**	**0.22**	**0.23**	**0.24**	**0.24**

For the United States the full sample runs from January 1998 until April 2012, the pre-Lehman from January 1998 until August 2008, and the post-Lehman from September 2008 until April 2012. For the euro area the full sample runs from January 2002 to April 2012, the pre-Lehman from January 2002 until August 2008, and the post-Lehman from September 2008 until April 2012. Coefficients of monetary surprises estimated with model (6); in bold the coefficients significant at the 95% level; standard errors are computed with the outer product.

Table 7 – Macroeconomic surprises on nominal and real rates before and after the Lehman collapse

US	**nom. rate**	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
pre-Lehman	Retail	**4.64**	**6.18**	**6.33**	**6.18**	**6.16**	**6.05**	**5.91**	**5.83**	**5.59**	**5.25**
post-Lehman	Retail	1.31	2.06	2.34	2.95	3.55	3.81	3.34	3.05	3.17	2.96
pre-Lehman	Job.claims	**-2.55**	**-2.40**	**-2.29**	**-2.10**	-1.72	-1.63	-1.53	-1.46	-1.49	-1.51
post-Lehman	Job.claims	-1.39	**-2.54**	**-4.13**	**-4.68**	**-4.38**	**-4.76**	**-5.19**	**-5.11**	**-5.00**	**-5.48**
pre-Lehman	CPI	0.53	1.05	1.27	1.45	1.65	1.75	1.71	1.64	1.62	1.64
post-Lehman	CPI	1.04	0.50	0.81	1.23	1.45	1.96	2.75	3.96	5.32	5.52
pre-Lehman	ISM	**2.94**	**4.02**	**4.20**	**4.16**	**4.13**	**4.04**	**4.00**	**3.89**	**3.58**	**3.18**
post-Lehman	ISM	**4.17**	**5.59**	**5.90**	**6.06**	**6.55**	**6.38**	**5.69**	**5.55**	**5.78**	**5.49**
US	**real rate**	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
pre-Lehman	Retail	-0.50	2.00	**3.28**	**3.84**	**4.04**	**4.04**	**3.95**	**3.83**	**3.69**	**3.56**
post-Lehman	Retail	-7.75	-2.42	-0.75	-0.31	-0.68	-0.70	-0.71	-0.66	-0.58	-0.45
pre-Lehman	Job.claims	-0.49	-1.82	-1.96	**-1.85**	**-1.66**	**-1.50**	**-1.37**	**-1.25**	**-1.15**	**-1.08**
post-Lehman	Job.claims	4.97	-2.14	-2.52	-2.34	-2.14	-2.06	-1.97	-1.88	-1.77	-1.65
pre-Lehman	CPI	-1.13	0.47	0.19	0.02	-0.01	0.05	0.14	0.24	0.33	0.41
post-Lehman	CPI	1.47	-5.05	-3.06	-1.61	-0.51	0.31	0.90	1.27	1.48	1.56
pre-Lehman	ISM	2.16	3.73	**3.75**	**3.45**	**3.22**	**2.99**	**2.84**	**2.74**	**2.66**	**2.60**
post-Lehman	ISM	-4.63	-1.52	-0.13	0.37	0.45	0.58	0.72	0.88	1.05	1.22
Euro area	**nom. rate**	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
pre-Lehman	Retail	0.99	1.10	1.20	1.21	1.14	1.04	0.96	0.91	0.89	0.91
post-Lehman	Retail	1.01	-0.24	-1.31	-2.08	-2.54	-2.79	-2.93	-3.01	-3.04	-3.05
pre-Lehman	Unenmp.	-14.21	-19.96	-24.83	-29.14	-32.70	-34.81	-35.07	-33.64	-30.93	-27.53
post-Lehman	Unenmp.	**-64.81**	-52.95	-42.18	-34.59	-30.40	-27.98	-25.95	-23.82	-21.55	-19.34
pre-Lehman	CPI	3.35	**3.35**	**3.42**	**3.40**	**3.24**	**3.02**	**2.80**	**2.61**	**2.44**	**2.30**
post-Lehman	CPI	2.85	2.72	2.44	2.02	1.54	1.08	0.70	0.42	0.23	0.11
pre-Lehman	Man.PMI	-4.37	-3.64	-2.50	-1.85	-1.94	-2.34	-2.61	-2.64	-2.43	-2.05
post-Lehman	Man.PMI	**4.34**	**4.46**	**4.52**	**4.50**	**4.40**	**4.24**	**4.03**	**3.80**	**3.58**	**3.40**
Euro area	**real rate**	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
pre-Lehman	Retail	2.96	2.52	2.09	1.66	1.24	0.89	0.62	0.44	0.33	0.27
post-Lehman	Retail	-2.02	-1.56	-1.12	-0.74	-0.43	-0.17	0.06	0.25	0.40	0.50
pre-Lehman	Unenmp.	-56.78	-50.39	-44.77	-41.19	-39.52	**-38.21**	**-36.12**	**-32.98**	**-29.01**	-24.65
post-Lehman	Unenmp.	-52.27	-39.88	-28.14	-17.33	-8.03	-1.12	2.94	4.30	3.43	0.93
pre-Lehman	CPI	5.37	4.65	3.93	3.24	2.59	2.00	1.48	1.04	0.67	0.36
post-Lehman	CPI	**9.13**	**9.22**	**9.19**	**8.88**	**8.30**	**7.70**	**7.23**	**6.93**	**6.80**	**6.78**
pre-Lehman	Man.PMI	7.78	7.25	6.80	6.53	6.35	6.03	5.40	4.46	3.28	1.98
post-Lehman	Man.PMI	1.57	2.16	2.62	2.91	3.02	3.04	3.02	2.99	2.96	2.93

For the United States the pre-Lehman period runs from January 1998 to August 2008, and the post-Lehman from September 2008 to April 2012. For the euro area the full sample runs from January 2002 until April 2012, the pre-L from January 2002 until August 2008, and the post-L from September 2008 until April 2012. Coefficients of macroeconomic surprises estimated with model (6); in bold the coefficients significant at the 95% level; standard errors are computed with the outer product.

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