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The inflation risk premium in the term structure of interest rates[1]

A dynamic term structure model based on an explicit structural macroeconomic framework is used to estimate inflation risk premia in the United States and the euro area. On average over the past decade, inflation risk premia have been relatively small but positive. They have exhibited an increasing pattern with respect to maturity for the euro area and a flatter one for the United States. Furthermore, the estimates imply that risk premia vary over time, mainly in response to fluctuations in economic growth and inflation.

JEL classification: E43, E44.

As markets for inflation-linked securities have grown in recent years, the prices of these instruments have become an important source of information for both central banks and financial market participants. Index-linked government bonds, for example, provide a means for measuring ex ante real interest rates at different maturities. In combination with yields on nominal government bonds, they can also be used to calculate the implied rate of inflation over the life of the bonds which would equate the real payoff from the two types of bonds. Such break-even inflation rates are commonly taken as a proxy for investors' expectations of future inflation, and are particularly useful because of their timeliness and simplicity. Moreover, implied forward break-even inflation rates for distant horizons are often viewed as providing information about central bank credibility: if the central bank's commitment to maintaining price stability is fully credible, expected inflation in the distant future should remain at a level consistent with the central bank's inflation objective.

Of course, break-even rates do not, in general, reflect expected inflation alone. They also include risk premia that compensate investors for inflation risk, as well as differential liquidity risk in the nominal and index-linked bond

[1] The results and much of the discussion in this article are based on Hördahl and Tristani (2007, 2008). The views expressed are those of the author and do not necessarily reflect those of the BIS. Thanks to Claudio Borio, Stephen Cecchetti, Frank Packer, Oreste Tristani and David Vestin for very helpful comments and suggestions and to Emir Emiray and Garry Tang for providing help with the graphs.

markets.[2] Presence of these risk premia complicates the interpretation of break-even inflation rates, and they should therefore in principle be identified and removed before assessing the information content of the break-even rates. Unfortunately, risk premia are not directly observable, so they must be estimated from data on observable quantities such as prices, yields and macroeconomic variables.

The purpose of this article is to build an empirical model of the inflation risk premium that delivers a "cleaner" measure of investors' inflation expectations embedded in government bond prices.[3] To keep the analysis manageable, liquidity risk premia are not considered explicitly here. However, in order to reduce the risk that the initial limited liquidity of index-linked bond markets might distort the results, information from index-linked bonds is excluded in the early part of the sample. In addition to quantifying the inflation risk premium, this article tries to shed some light on its determinants by explicitly linking prices of real and nominal bonds to macroeconomic fundamentals and to investors' attitudes towards risk. To allow for a comparison across the world's two largest economies, estimates are constructed using data for both the United States and the euro area.

What is the inflation risk premium?

Inflation risk induces premia in bond yields …

Inflation risk premia arise from the fact that investors holding nominal assets are exposed to unanticipated changes in inflation. In other words, the real payoff – which is what investors ultimately care about – from holding a nominal asset over some time period depends on how inflation evolves over that period, and investors will require a premium to compensate them for the risk associated with inflation fluctuations that they are unable to forecast.

Most people tend to think that this compensation, or inflation risk premium, should be positive and possibly increase with the time horizon of the investment. However, economic theory tells us that this need not be the case. For example, in many simple economic models, the price of an asset depends on the covariance of its payoff with real consumption growth. In this type of model, prices of nominal assets, such as nominal bonds, will therefore depend in part on the covariance of consumption and inflation. It is the sign of this covariance that determines the sign of the inflation risk premium: if consumption growth covaries negatively with inflation, so that consumption growth tends to be low when inflation is high, then nominal assets are more risky and investors will demand a positive premium to hold them. If, on the

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[2] For example, the daily turnover and the total amounts outstanding are generally considerably lower in index-linked bond markets than in nominal bond markets. This implies that there is a higher risk that investors in index-linked bond markets may encounter problems when trying to quickly exit positions at prevailing market prices, in particular during turbulent conditions, compared to investors in nominal bond markets. Moreover, such liquidity risks are especially high during the first few years after the initial launch of index-linked bonds in a market.

[3] In addition, estimates of the inflation risk premium may be of interest independently of break-even inflation considerations, as they may signal changes in perceived inflation risks or shifts in investors' aversion to inflation risk.

other hand, the covariance is positive, then holding nominal assets will partially hedge negative surprises to consumption, and investors would be willing to do so for a lower expected return, implying a negative inflation premium.[4] To complicate matters, this simple relationship need not hold in more elaborate models.

Irrespective of the sign of the inflation risk premium, from the perspective of the term structure of interest rates, it complicates the decomposition of nominal interest rates into its component parts. Consider, for example, a two-period bond. In somewhat simplified terms, we can express the (continuously compounded) yield on this bond as[5]

$$Ynom = rreal^{e} + RRP + infl^{e} + INFRP \qquad (1)$$

The first two components make up the two-period real yield: $rreal^{e}$ denotes the expected average one-period real interest rate during the two periods until the bond matures, and RRP is the real premium due to risk associated with the evolution of the one-period real rate over this period. The third term, $infl^{e}$, is the average expected inflation rate during the two periods, which brings the expected real return of the nominal bond into line with that of the corresponding real bond. The final term, $INFRP$, is the inflation risk premium. The sum of the real risk premium and the inflation risk premium makes up the total term premium (also called the nominal risk premium), which is the quantity that separates the nominal bond yield from the expected average one-period nominal interest rate during the life of the bond.

Looking at equation (1), we can immediately compute the break-even inflation rate as the difference between the nominal yield and the real yield:

$$\begin{aligned} BEI &= Ynom - rreal^{e} - RRP \\ &= infl^{e} + INFRP \qquad (2) \end{aligned}$$

… which affect break-even inflation rates

Equation (2) clearly shows that the inflation risk premium introduces a wedge between the break-even rate and investors' inflation expectations.

Available empirical evidence

Because theory provides little guidance with respect to either the sign or the size of inflation risk premia, measuring this important quantity has spawned a large empirical literature. In recent years, a number of studies have used "no-arbitrage" term structure models to estimate inflation risk premia. In this type of model, bonds of different maturities (nominal as well as real) are priced in an internally consistent way, such that any trading strategy based on these prices cannot generate risk-free profits.

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[4] More formally, in standard models with investors exhibiting constant relative risk aversion, the price will depend on the covariance between the ratio of future and current marginal utility of consumption (ie the stochastic discount factor) and the reciprocal of inflation. If this covariance is negative, the inflation risk premium is positive.

[5] As mentioned above, this abstracts from any liquidity premia. For simplicity, it also disregards possible influences due to institutional and technical factors, as well as effects resulting from Jensen's inequality terms (which are in the order of only a few basis points in the cases considered here).

The available empirical evidence on the properties of inflation risk premia is somewhat mixed. Studies that cover very long sample periods and that do not include information from index-linked bonds to help pin down the dynamics of real yields often report sizeable inflation risk premia. For example, using a structural economic model, Buraschi and Jiltsov (2005) find that the 10-year US inflation risk premium averaged 70 basis points from 1960.[6] They also find that the inflation premium was highly time-varying, and that by the end of their sample it had fallen to relatively low levels. Ang et al (2008) estimate a term structure model in which inflation exhibits regime switching using US inflation and nominal yield data, and report a large and time-varying inflation risk premium (on average, around 115 basis points for the five-year maturity over their 1952–2004 sample).

In papers that focus on more recent periods and in those that utilise information embedded in index-linked bonds, inflation risk premium estimates tend to be relatively small, although still mostly positive. Durham (2006) estimates a no-arbitrage model using US Treasury inflation-indexed bond data and finds that the 10-year inflation premium hovered around a slightly positive mean from 2003 onwards.[7] D'Amico et al (2008) apply a similar model to data from 1990 onwards, and report a moderate-sized positive 10-year inflation premium (around 50 basis points on average) that is relatively stable. However, they also find that their results are sensitive to the choice of date from which index-linked bond data are included.

Recent empirical evidence points to small positive inflation premia

The available empirical evidence relating to euro area data is more limited. In fact, apart from the papers on which this article is based, there appears to be only one study focusing on the euro area.[8] García and Werner (2008) apply a term structure model similar to that used by D'Amico et al (2008) on euro real and nominal yields, supplemented with survey data on inflation expectations. Their estimates suggest that the inflation premium at the five-year horizon has averaged around 25 basis points since the introduction of the euro, and that it has fluctuated only mildly over time. Hence, their results seem to be in line with those of Durham (2006) and D'Amico et al (2008), which point to a relatively modest, but positive, long-term inflation risk premium in recent years.

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6 All quantitative risk premium estimates mentioned are in terms of (annualised) yield, rather than eg holding period returns.

7 Prior to 2003, Durham (2006) obtains a 10-year inflation premium that was mostly negative. This is probably due to sizeable liquidity premia in this part of the sample period, which would have tended to raise the index-linked bond yield and therefore produce negative inflation premia to fit the resulting low level of break-even inflation rates.

8 More empirical evidence is available for UK data, as a result of the longer history of index-linked bonds in the UK market. Applying a no-arbitrage model to UK data, Remolona et al (1998) find that the two-year inflation risk premium was relatively stable, averaging around 70 basis points after 1990. Risa (2001) also finds a large and positive UK inflation risk premium, based on a similar model. However, Evans (2003) obtains sizeable negative premia using a model that includes regime switching in the term structure.

A macro-finance approach to modelling the inflation risk premium

Much of the available empirical no-arbitrage term structure literature, including most of the studies mentioned above, has modelled yields and associated premia based on a set of unobservable factors. For example, a standard specification among the most widely used class of models ("affine term structure models") assumes that three unknown factors determine the dynamics of bond yields of all possible maturities. Specifically, given certain assumptions regarding the properties of the unobservable factors, the absence of arbitrage opportunities implies that all yields are "affine" – ie linear plus a constant – functions of the factors. This simplicity has made affine term structure models popular for empirical analysis of bond yields. The fact that such models also seem to successfully capture important features of the data has added to their attractiveness; see eg Dai and Singleton (2000, 2002) and Duffee (2002). The downside is that, since the factors are simply linear combinations of the yields that go into the estimation, these models do not allow us to learn much about the way economic fundamentals drive bond yields and risk premia across various maturities.

Bond yields are modelled jointly with the macroeconomy

In order to overcome this, the direction taken here is to model the dynamics of bond yields jointly with the macroeconomy.[9] Specifically, the approach sets up a small-scale model that describes key macro variables (inflation and real output) and how they interact with monetary policy (see box). The real and nominal interest rate term structures are added in such a way that they are consistent with expected interest rate developments due to central bank policy moves, while at the same time allowing for flexible risk premia linked to macroeconomic risks. In this way, movements in bond yields and in term premia (as well as their decomposition into real and inflation premia) can be explained in terms of developments in macroeconomic variables and monetary policy. The cost is that, as the model is extended to include macroeconomic variables, the estimation process becomes more complex and time-consuming. In addition, the economic structure imposes restrictions on the factors that price bonds in the model, which may make it more challenging to fit bond yields well compared to an approach where the factors are unobservable and hence maximally flexible. On the other hand, insofar as the macro model is able to provide a reasonable characterisation of key features of the economy, the addition of macro information may be useful for accurately pinning down the dynamics of the term structure.

Once the macroeconomic framework is set up to describe the dynamics of output, inflation and the monetary policy rate, as described by (3)–(5) in the box, the model can be solved for the rational expectations equilibrium using standard numerical techniques. As a result, one obtains expressions that describe how the key variables in the economy – the "state variables" – evolve

[9] This approach is a development of the pioneering work by Ang and Piazzesi (2003). The general setup of the model is discussed in some detail in Hördahl et al (2006), while the particular specification used here is described in Hördahl and Tristani (2007, 2008).

Macroeconomic setup

The approach taken here to describe the macroeconomy relies on the so-called "new neo-classical synthesis", which arguably has come to dominate macroeconomic modelling in academia as well as at central banks. This approach combines the real business cycle framework that describes how real variables drive changes in output with the dynamic pricing setup in New Keynesian models. Simple standard versions of this modelling approach boil down to just two equations, which describe the dynamics of output and inflation.[1] Typically, the output gap x_t – ie the deviation of actual output from "potential" (efficient) output – is assumed to depend on expectations of the output gap in the future, on the lagged output gap, and on the next period's expected short-term real interest rate (nominal rate r_t minus expected inflation rate $E_t[\pi_{t+1}]$):

$$x_t = \mu_x E_t[x_{t+}] + (1 - \mu_x)x_{t-} + \zeta_r(r_t - E_t[\pi_{t+1}]) + \varepsilon_t^x \tag{3}$$

The leads and lags of the output gap can be thought of as capturing consumption smoothing behaviour and consumption habits, respectively, among investors (consumption is equal to output in standard simple models). The presence of the expected real rate in (3) allows consumption to shift over time in response to interest rate movements. The last term is a demand shock (eg a preference shock). Inflation is specified in a similar fashion, with expected future inflation as well as lagged inflation included to capture price stickiness and inflation inertia:

$$\pi_t = \mu_\pi E_t[\pi_{t+}] + (1 - \mu_\pi)\pi_{t-} + \delta_x x_t + \varepsilon_t^\pi \tag{4}$$

In addition, the output gap enters the inflation equation, so that, for example, positive demand shocks that push output above potential can have inflationary consequences (in a microfounded model, this term would arise because monopolistic competition implies that prices will be set as a markup on marginal cost). Inflation is also assumed to be affected by supply shocks, ε_t^π, such as oil price shocks and other so-called cost push shocks.

With the specification of output and inflation in place, the final building block specifies how monetary policy is conducted. Specifically, it is assumed that a forward-looking Taylor (1993) rule is capable of describing how the central bank sets the short-term nominal interest rate:

$$r_t = \beta(E_t[\pi_{t+}] - \pi_t^*) + \gamma x_t + \rho r_{t-1} + \varepsilon_t^r \tag{5}$$

According to this rule, the policy rate depends on whether inflation is higher or lower than the level targeted by the central bank (π_t^*), which is allowed to vary over time, as well as on the level of the output gap, x_t. The lagged interest rate is included to account for "interest rate smoothing" behaviour by the central bank, and the last term in (5) denotes a monetary policy shock.[2] The inflation target, which is unobservable, is simply assumed to follow a first-order autoregressive process.

[1] The model is here specified directly at the aggregate level, meaning that the microfoundations, such as the specific preferences of individuals, are not explicitly modelled. However, the specification used is consistent with the setup that would have obtained if the model had been derived from first principles. [2] Like all other shocks in the model, the policy shock is assumed to be normally distributed with constant variance.

over time. This is useful in the context of specifying the term structure of interest rates, because bond yields will depend on expectations of future monetary policy rates, which, in turn, will depend on the way the economy is expected to evolve. Moreover, the law of motion of the state variables implied by the model solution turns out to be of the same form as the assumed dynamics of the unobservable factors in standard affine term structure models, as discussed above.[10] Because the dynamics are identical, the same bond pricing formulae will apply in this setup as in standard affine models, once the

[10] Specifically, both the state variables in our setup and the unobservable factors in an affine term structure model will follow AR(1) processes.

assumption of absence of arbitrage opportunities has been imposed. This means that bond yields (nominal as well as real) will be linear functions of the macroeconomic state variables. In imposing the no-arbitrage assumption, a key element is the specification of the so-called “market prices of risk”. As the name suggests, these will determine how risks in the economy are priced as premia in bonds, reflecting investors’ aversion to various sources of risks. Here, the market prices of risk are allowed to vary over time, by virtue of being specified as linear functions of the macroeconomic state variables. Specifically, the prices of risk – and by extension bond risk premia – will be linear functions of inflation, the output gap, the inflation target and the policy rate. As a result, the inflation risk premium will also vary with the level of these variables.

Inflation risk premia estimates

Data and estimation considerations

The macro-finance term structure model described above is estimated separately for the United States and for the euro area. In addition to bond yields, the estimation requires data for inflation and the output gap, which effectively limits the frequency of observation. In this article, the data are therefore sampled at a monthly frequency. Inflation is taken to be year-on-year CPI inflation (HICP in the case of the euro area), and the output gap is measured as real GDP (in logs) in deviation from an estimate of potential output.[11] Data revisions are not explicitly taken into account, and the empirical results should therefore be viewed as providing a historical characterisation of the way macroeconomic factors drive movements in bond yields, rather than as a real-time exercise. The period covered in the estimations is January 1990 to July 2008 in the case of the United States. For the euro area, the introduction of the euro provides a natural starting date, so in this case the sample period is limited to January 1999 to July 2008.

In order to estimate the dynamics of the nominal term structure, seven different nominal (zero coupon) yields ranging in maturity from one month to 10 years are included in the estimation. Moreover, because it is important to also accurately pin down the behaviour of the real term structure, four real yields with maturities between three and 10 years enter as well.[12] Although

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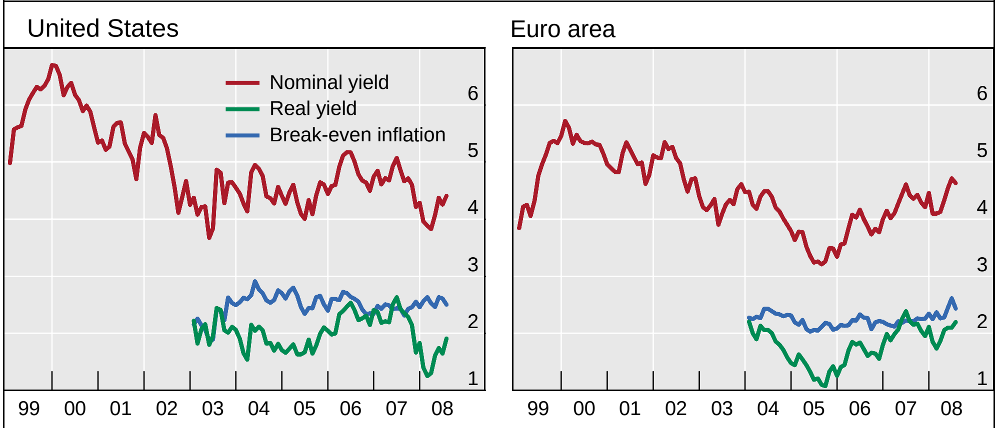
[11] For the United States, the Congressional Budget Office’s estimate of potential output is used. Such an official measure is not available for the euro area, so in this case potential output is measured as the quadratic trend of GDP growth, similar to Clarida et al (1998). (Because GDP data are released on a quarterly basis, monthly values are obtained by means of time series forecasts and interpolations.) The results do not appear to be sensitive to the way the output gap is measured. A re-estimation of the model for the United States based on a gap measured with a quadratic trend resulted in only very minor changes to the estimated premia and inflation expectations.

[12] The US real and nominal term structure data consist of zero coupon yields based on the Nelson-Siegel-Svensson (NSS) method, which are available from the Federal Reserve Board. The real zeros are made available with a lag of a few months, and the final few months of data are therefore obtained directly using NSS estimates based on available index-linked bond prices (obtained from Bloomberg). For the euro area, the nominal yields are based on the NSS method applied to German data, as reported by the Deutsche Bundesbank. For large

Ten-year rates

In per cent



Sources: Deutsche Bundesbank; Federal Reserve; Bloomberg; author's calculations. Graph 1

real yield dynamics could in principle be estimated indirectly using only nominal yield data, the inclusion of real yields is likely to result in more accurate estimates. However, while nominal yield data are available from the beginning of the two sample periods, real zero coupon yields are not. Moreover, due to liquidity problems in the US index-linked bond market during the first few years (see eg D'Amico et al (2008)), real yields are included in the US estimation only as of 2003 to reduce the risk of distorting the results. For similar reasons, euro area real yields are included only from 2004. Graph 1 plots nominal and real 10-year yields used in the estimation, along with the break-even inflation rate obtained by taking the difference between these two yields.

In addition to macro and yield information, data on inflation and interest rate expectations from surveys are used in the estimation.[13] As argued by Kim and Orphanides (2005), this is useful to help pin down the dynamics of key variables in the model. Specifically, by including information from survey data, parameter configurations implying model expectations that deviate from survey expectations are penalised in the estimations.

The model is estimated using the maximum likelihood method, based on the Kalman filter (due to the presence of unobservable variables). Because there is a large number of parameters involved in the estimation, it is fruitful to introduce priors and proceed by relying on Bayesian estimation methods. This makes it possible to exploit prior information on structural economic

parts of the maturity spectrum, the German nominal bond market is seen as the benchmark for the euro area. Real euro area zero coupon rates are obtained using the NSS method, based on prices of AAA-rated euro area government bonds linked to the euro area HICP issued by Germany and France (obtained from Bloomberg).

13 The following survey data are included in the estimations on US data: the expected three-month interest rate two quarters ahead, four quarters ahead and during the coming 10 years, and expected CPI inflation for the same horizons (source: the Philadelphia Fed's quarterly Survey of Professional Forecasters). The euro area survey data consist of forecasts for inflation obtained from the ECB's quarterly Survey of Professional Forecasters, and three-month interest rate forecasts available on a monthly basis from Consensus Economics. The inflation forecasts refer to expectations of HICP inflation one, two and five years ahead. The survey data for the short-term interest rate correspond to forecasts three and 12 months ahead.

relationships available from previous studies. Moreover, the inclusion of prior distributions brings an added advantage in that it tends to make the optimisation of the highly non-linear estimation problem more stable.

Characteristics of inflation risk premia

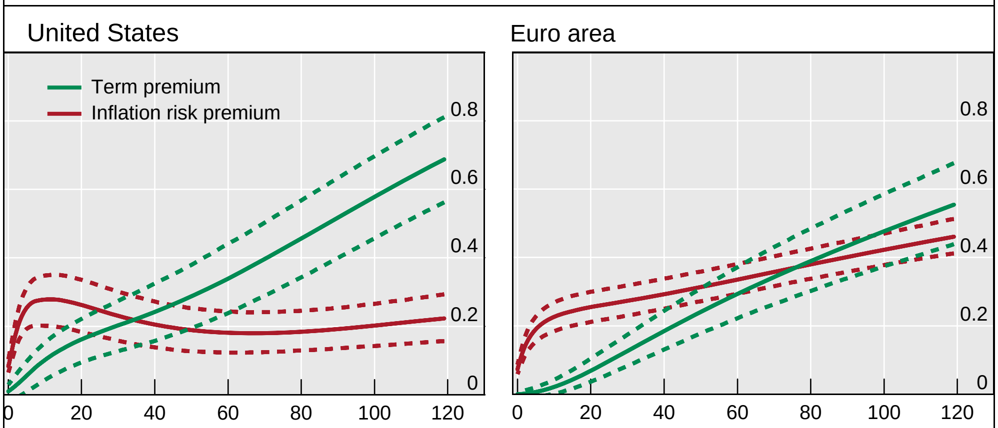
Given the parameter estimates obtained using the approach described above, any possible combination of state variables implies a specific term premium on nominal bonds for any maturity, as well as a decomposition of the term premium into a real risk premium and an inflation risk premium.

Inflation premia are positive on average …

Graph 2 plots the average estimated term premium and inflation risk premium across all maturities up to 10 years. Both premia are positive on average in the United States as well as the euro area.[14] The US term premium is estimated to be slightly larger across all maturities compared to that of the euro area, although the difference is not statistically significant. The inflation premium is found to be somewhat lower on average in the United States than in the euro area, with the difference being significant from a statistical point of view for longer maturities. Moreover, the maturity profile of US inflation premia is estimated to be flatter than that of the euro area. As a result, for long-term maturities most of the US term premium seems to be due to compensation for real rate uncertainty, similar to results reported by Durham (2006) and D'Amico et al (2008), while in the euro area the inflation premium accounts for most of the total average term premium. One possible factor behind a higher US real risk premium compared to the euro area might be the greater variability of US short-term interest rates, which may have resulted in perceptions of higher real

Term structure of average risk premia

In per cent



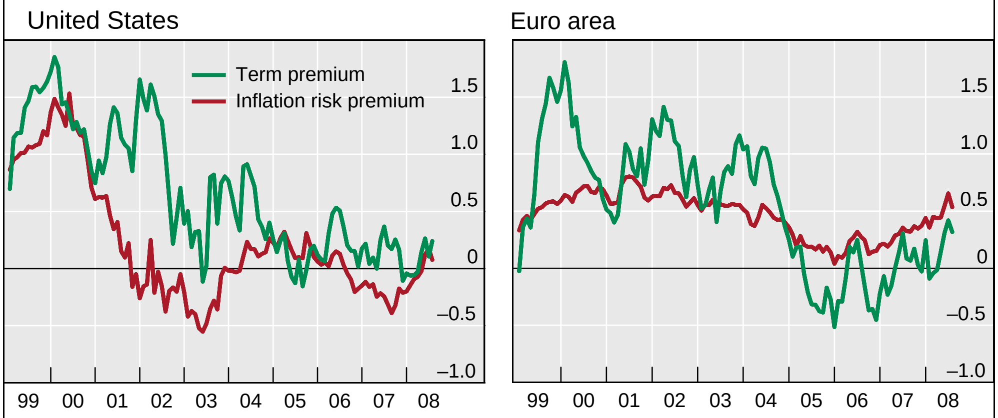
The term premium is the sum of the real risk premium (not shown) and the inflation risk premium. Horizontal axis refers to the horizon in months. The dashed lines show 95% Bayesian confidence intervals around the median (based on 50,000 draws from the posterior distribution).

Source: Author's calculations. Graph 2

[14] While in the case of the United States the data extend back to 1990, the period covered in Graphs 1–4 is 1999 onwards. This is in order to facilitate comparison with results for the euro area.

Estimated 10-year risk premia

In per cent



The term premium is the sum of the real risk premium (not shown) and the inflation risk premium.

Source: Author's calculations. Graph 3

interest rate risk in the United States and hence higher required compensation to bear this risk.[15]

… and vary over time

The dynamics of the estimated risk premia are displayed in Graph 3, with a focus on the 10-year maturity. The US 10-year term premium has tended to decline during the period covered in the graph, and has remained close to zero in recent years, a feature that has also been found by D'Amico et al (2008), among others. Falling term premia have been seen as an important ingredient in explaining Greenspan's "conundrum" of very low long-term bond yields in the past few years (Greenspan (2005), Kim and Wright (2005), Bernanke (2006)). Our results indicate that the decline in the term premium was due to a fall in both the real premium and the inflation premium.[16] In particular, the US inflation premium displayed a sharp drop in the first couple of years of the new millennium. This coincided with a pronounced fall in US inflation and growing concerns about deflationary pressures in the wake of sharp declines in equity prices and an economic downturn. In such an environment, investors apparently became less concerned about inflation risk, which resulted in lower required return to take on such risk.

The estimates of the 10-year term premium in the euro area show that this has fallen in line with the US term premium. However, much of this has been

[15] For example, since 1999, US one-month nominal interest rates have on average been 80% more volatile than comparable euro area rates. As a result, US ex post one-month real rates have also been more volatile than in the euro area. By contrast, the volatility of US month-on-month inflation has been about the same as in the euro area.

[16] As previously mentioned, the analysis does not take into account institutional or technical factors. Such factors include heavy purchases of government securities by foreign central banks and other state institutions in recent years, which may have influenced government bond prices. To the extent that such factors have exerted downward pressure on bond yields unrelated to fluctuations in macroeconomic variables, this is likely to show up in the results as lower estimated risk premia. Moreover, it has been argued that this type of activity has been particularly pervasive for US Treasuries in recent years, suggesting that the impact may have been especially pronounced on Treasury yields and, by extension, on estimated US risk premia.

attributable to a declining real premium, while the inflation premium has remained relatively more stable around a small positive mean. These estimates of long-term euro area inflation risk premia are broadly in line with those reported by García and Werner (2008), who use an affine model based on unobservable factors. The fact that different models result in similar inflation premia estimates suggests that the results in this dimension may be reasonably robust.

Premium-adjusted break-even rates

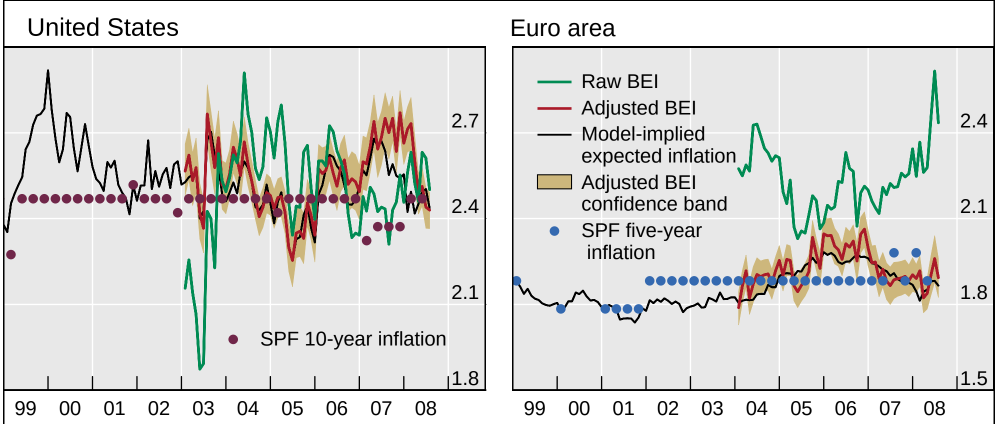
Premium-adjusted break-even rates …

As mentioned above, inflation risk premia introduce a wedge between break-even inflation rates and actual inflation expectations among investors. Given the inflation risk premium estimates obtained here, it is therefore possible to strip out this component to obtain premium-adjusted break-even inflation rates, which provide a model-consistent measure of average expected inflation during the time to maturity. Graph 4 plots raw and premium-adjusted 10-year break-even inflation rates in the United States and the euro area for the periods during which reliable estimates of zero coupon real rates are available (as discussed above).

Reflecting the small magnitude of the estimated premia, the raw and adjusted break-even rates tend to be relatively close to one another, in particular for the United States. With euro area inflation premia estimated to be somewhat larger than in the United States on average, the euro area adjusted

Ten-year break-even rates and inflation expectations

In per cent per year



BEI denotes break-even inflation rates. The raw BEI is the simple difference between 10-year nominal bond yields and 10-year real yields, while the adjusted BEI subtracts the estimated 10-year inflation risk premium from this quantity. The model-implied expected inflation is the average expected inflation rate over the next 10 years, as implied by the estimated macro dynamics of the model. SPF inflation denotes survey expectations of inflation during the next 10 years (for the United States) and five years ahead (for the euro area), as reported in the Survey of Professional Forecasters of the Federal Reserve Bank of Philadelphia and the ECB, respectively. Adjusted BEI confidence bands show 95% Bayesian confidence intervals around the median premium-adjusted BEI (based on 50,000 draws from the posterior distribution).

Sources: ECB; Federal Reserve; author's calculations. Graph 4 break-even rate is consequently also lower relative to the raw rate.[17] In fact, while the raw euro area break-even rate has been fluctuating consistently above a level of 2% since 2004, the premium-adjusted measure has been close to and mostly below 2%, suggesting long-term euro area inflation expectations more in line with the ECB's price stability objective than would have been the case had the unadjusted break-even rate been taken to represent expected inflation.

Graph 4 also displays the estimated model-implied average expected inflation rate over the next 10 years at each point in time, which is available over the entire sample periods. This is the expected 10-year inflation rate produced by the macro dynamics of the model, which would fully coincide with the premium-adjusted break-even rate if all yield measurement errors were always zero. While this is not the case, the difference is very small, in the order of a few basis points, indicating that the model successfully captures the dynamics of both nominal and real yields. An exception seems to be the last year of the sample in the case of the United States, when a noticeable difference emerges between the two measures. This may have been due to sharp movements in Treasury yields (eg flight to safety) resulting from the outbreak of financial turmoil starting in mid-2007, which the model is ill-equipped to handle.

In addition, Graph 4 reports measures of long-horizon inflation expectations from available survey forecasts: 10-year US inflation expectations from the Federal Reserve's Survey of Professional Forecasters (SPF) and five-year euro area inflation expectations from the ECB's SPF. The results indicate that the model does well in capturing the level and broad movements of investors' long-term inflation survey expectations, which is not surprising given their inclusion in the estimations. In the case of the euro area, where the premium-adjusted break-even rate has differed more from its raw counterpart than in the United States, the adjusted break-even rate is much closer to the survey forecasts than the unadjusted rate. With respect to the US case, the survey data provide some justification for the very low US inflation risk premia estimates obtained. Since 2003, the raw US 10-year break-even rate has been relatively well aligned with the survey measure, suggesting that the inflation premium needs to be small to result in an adjusted break-even rate close to the survey expectations.

… are close to survey inflation expectations

The inflation risk premium and the macroeconomy

In order to gain some insight into what the underlying drivers of inflation risk premia are, it is useful to investigate how they evolve in response to changes in the macroeconomic state variables. Ultimately, all time variation in the estimated premia will be due to movements in these variables. It turns out that two of the state variables are the main drivers of inflation premia in the United

[17] The same result holds for five-year forward break-even rates five years ahead, a common indicator of market inflation expectations for distant horizons. For the United States, the premium-adjusted version of this forward break-even rate has differed little from the raw version, while in the case of the euro area the adjustment has generally resulted in a significantly lower level compared to the raw series (see BIS (2008, pp 112–13)).

Inflation and output movements drive developments in inflation premia ...

States as well as in the euro area: the output gap and inflation. Broad movements in the 10-year inflation risk premium largely match those of the output gap, while higher-frequency fluctuations in the premium seem to be aligned with changes in the level of inflation.

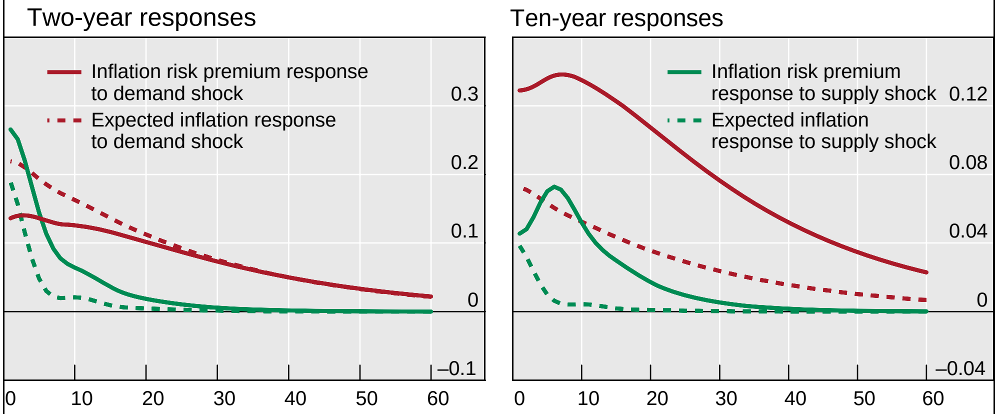
Movements in the output gap and in inflation are due to combinations of the structural shocks in the model, so, to better understand the ultimate determinants of premia, it is necessary to examine their reaction to such shocks. One of the advantages of the modelling strategy adopted here is that it makes it possible to compute impulse response functions of yields and associated premia to the underlying macro shocks. Graphs 5 and 6 show US and euro area responses of inflation risk premia and expected inflation to demand and supply shocks. The left-hand panels refer to a two-year horizon and the right-hand panels to a 10-year horizon. These graphs show that the responses of inflation premia to demand shocks (ie shocks to the output gap in equation (3)) are much more persistent than responses to supply shocks (ie shocks to inflation in equation (4)). Intuitively, this reflects the fact that the effects on inflation and output from demand shocks are substantially longer-lasting than those from supply shocks.

... with demand shocks having persistent effects ...

Looking at the results in more detail, a positive shock to US aggregate demand, corresponding to a 1 percentage point increase in the shock to the output gap in equation (3), pushes up the 10-year inflation premium by around 13 basis points (Graph 5, right-hand panel), possibly reflecting perceptions of a higher risk of upside inflation surprises as the output gap widens. A positive demand shock also raises the average expected inflation rate by about 7 basis points, resulting in an overall increase in the 10-year break-even rate (ie the sum of the two responses) of some 20 basis points. At the two-year horizon (Graph 5, left-hand panel), the effect on the break-even rate from a demand shock is even larger, at around 35 basis points on impact, but now the bulk of the response is due to rising inflation expectations, while the inflation premium

US impulse responses

In per cent



The demand shock corresponds to a 1 percentage point increase in the shock to the output gap in equation (3), while the supply shock is a 1 percentage point increase (in annualised terms) in the shock to inflation in equation (4). Horizontal axis measures the horizon of the responses in months.

Source: Author's calculations. Graph 5

response is similar to the 10-year case. Demand shocks therefore seem to induce parallel shifts in the inflation premium, while inflation expectations react much more strongly for short maturities than for long.

... while the impact of supply shocks is short-lived

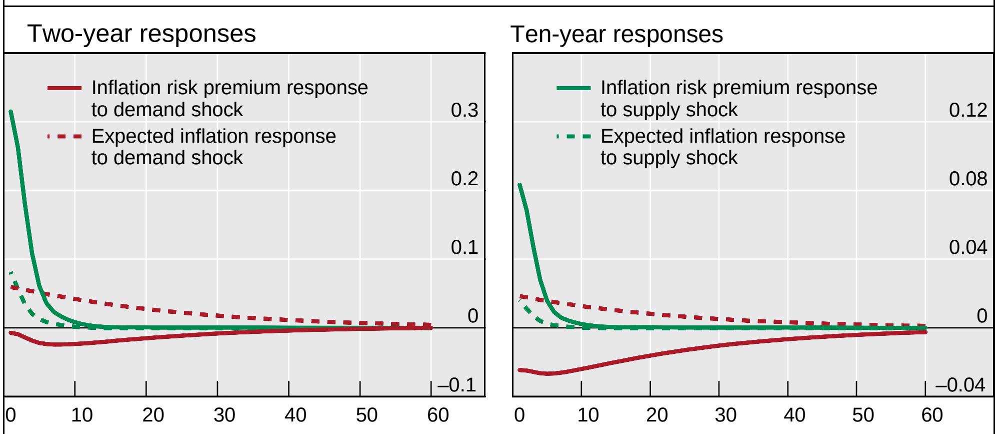
The responses to supply shocks in Graph 5 (corresponding to a 1 percentage point increase in the shock to inflation in equation (4)) are clearly less pronounced and less persistent than for demand shocks. Nonetheless, the short-term reaction of both expected inflation and inflation risk premia at the two-year horizon is sizeable. This suggests that investors become more averse to inflation risk as inflation rises.

As in the United States, a positive demand shock also raises expected inflation in the euro area, and more so at the two-year horizon than at the 10-year horizon (Graph 6). However, in contrast to the US case, the inflation premium response is uniformly negative, albeit small. In terms of the response of euro area break-even inflation to demand shocks, the two effects largely cancel out. Given that the inflation risk premium accounts for a sizeable portion of the overall term premium, this negative response of the inflation premium to demand shocks appears to be in line with evidence from Germany prior to the introduction of the euro, as documented in Hördahl et al (2006), where term premia reacted negatively to positive demand shocks. A possible explanation for this finding could be that investors become more willing to take on risks – including inflation risks – during booms, while they require larger premia during recessions.[18]

With respect to euro area responses to a supply shock, the results in Graph 6 are qualitatively similar to those for the United States. A 1 percentage point upward shock to aggregate supply raises the two-year break-even rate by around 40 basis points on impact, an effect that quickly wears off. Most of this

Euro area impulse responses

In per cent



The demand shock corresponds to a 1 percentage point increase in the shock to the output gap in equation (3), while the supply shock is a 1 percentage point increase (in annualised terms) in the shock to inflation in equation (4). Horizontal axis measures the horizon of the responses in months.

Source: Author's calculations. Graph 6

[18] Such effects have been found elsewhere. Piazzesi and Swanson (2008), for example, report strongly countercyclical risk premia based on estimates on federal funds futures prices.

increase is due to a higher two-year inflation premium (over 30 basis points). At the 10-year horizon, the break-even response is similarly short-lived and substantially smaller at around 10 basis points, predominantly due to the inflation premium.

Conclusion

This article estimates inflation risk premia using a dynamic term structure model based on an explicit structural macroeconomic model. The identification and quantification of such premia are important because they introduce a wedge between break-even inflation rates and investors' expectations of future inflation. In addition, inflation risk premia per se may provide useful information to policymakers with respect to market participants' aversion to inflation risks as well as to their perceptions about such risks.

The results show that inflation risk premia in the United States and in the euro area are on average positive, but relatively small. Moreover, the estimated premia vary over time, mainly in response to changes in economic activity, as measured by the output gap, and inflation. The estimates suggest that fluctuations in output drive much of the cyclical variation in inflation premia, while high-frequency premia fluctuations are mostly due to changes in the level of inflation.

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