Functional Shocks to Inflation Expectations and Real Interest Rates and Their Macroeconomic Effects

Christina Anderl, Guglielmo Maria Caporale

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Abstract

This paper applies a recently developed method (Inoue and Rossi, 2021) to estimate functional inflation expectations and ex-ante real interest rate shocks, and then examines their macroeconomic effects in the context of a Functional Vector Autoregressive model with exogenous variables (Functional VARX). Monthly data from January 1998 to May 2023 for the US, the UK and the euro area are used for the analysis. The estimated impulse responses show significant effects of the functional shocks on both inflation and output. In addition, threshold functional local projections indicate that the effects are nonlinear and depend on central bank credibility. Further, inflation expectations shocks have similar effects to supply (demand) ones when they are driven by long-term (short-term) changes. In the presence of an inverted (steepening) real interest rate term structure, the effects are inflationary (deflationary) and expansionary (recessionary). Finally, the responses of inflation, output and the policy rate are driven primarily by the slope and curvature factors of the term structure shocks, which contain important information not captured by traditional scalar shocks.

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1. Introduction

There is a widespread consensus among academics and policymakers that inflation expectations affect the transmission mechanism of monetary policy and are a key determinant of inflation and economic activity (Alessi and Onorante, 2012). However, the empirical evidence on their macroeconomic effects is relatively limited. The existing literature focuses either on the anchoring of long-term expectations and their role in the monetary policy transmission to output and inflation (Clark and Davig, 2011; Neri, 2021), or on the possibly asymmetric impact of shocks to short-term expectations (Ascari et al., 2023), but it does not examine their combined effects. Inflation expectations are also a component of *ex-ante* real interest rates, which are an important driver of business cycles (King and Watson, 1996; Neumeyer and Perri, 2005) and of commodity prices (Akram, 2009), but again the evidence on the macroeconomic impact of shocks to this variable is rather scarce compared to that on other types of shocks (Bhuiyan and Lucas, 2007).

The aim of the present study is to shed new light on these issues by using an approach recently developed by Inoue and Rossi (2021), which estimates inflation expectations and *ex-ante* real interest rate shocks as exogenous shifts in an entire function, namely in their term structure at short-, medium- and long-term horizons (Aruoba, 2020). This method can provide insights into the degree of anchoring of inflation expectations as well as the transmission mechanism of both conventional and unconventional monetary policies (Holsten et al., 2017). Specifically, we use monthly data from January 1998 to May 2023 for the US, the UK and the euro area first to model inflation expectations and *ex-ante* real interest rate shocks as functional shifts, and then to assess their macroeconomic effects in the context of a Functional Vector Autoregressive model with exogenous variables (Functional VARX) by means of impulse responses as well as nonlinear functional local projections. In particular, for the UK and the euro area we estimate survey-based term structures using yield curve models, whilst for the US we use the Aruoba Term Structure of Inflation Expectations (ATSIX) dataset available from the Federal Reserve Bank of Philadelphia website.

The remainder of the paper is structured as follows: Section 2 reviews the existing literature on inflation expectations and real interest rate shocks, Section 3 outlines the methodology, Section 4 presents the empirical results, and Section 5 offers some concluding remarks.

2. Literature Review

The main strand of the literature concerned with inflation expectations assesses the degree of anchoring. Hachula and Nautz (2018) use macroeconomic news announcement (MNA) surprises as a proxy variable to identify US macro news shocks in a Structural VAR model without long-run restrictions and find that macroeconomic news shocks have a significant impact on short-term (but not on long-term) de-anchoring. Nautz et al. (2019), who use a similar approach but distinguish between macro news shocks and target shocks, confirm that US inflation expectations are anchored in the long run given the long-run neutrality of macro news shocks. By contrast, recent shifts in long-term inflation expectations are the result of changes in expectations about the Federal Reserve's inflation target. Empirical investigations of inflation expectations have traditionally been based on the New Keynesian Phillips Curve (NKPC), for which expectations measures obtained from surveys are found to be a better approximation than those based on the rational expectations assumption (Roberts, 1997; Adam and Padula, 2011). Survey-based inflation expectations are known to outperform market-based measures in terms of their forecasting performance and seem to be more informative for macroeconomic variables such as US inflation (Fuhrer, 2011; Faust and Wright, 2013).

The literature focusing on the macroeconomic impact of inflation expectations shocks confirms their key role. Leduc et al. (2007) use a VAR model with a recursive identification scheme in which inflation expectations come first in the ordering and find that one-off exogenous increases in this variable lead to higher inflation even ten years after the initial impact.[1] Neri (2021), instead, uses a Structural VAR model with sign restrictions to identify inflation expectations shocks, and find that they have been a significant determinant of disinflationary and recessionary periods in the euro area. Diegel and Nautz (2021) use the same type of framework and conclude that long-term inflation expectations are particularly important to identify monetary policy shocks and play a key role in the transmission mechanism. Barrett and Adams (2022) use the reduced-form coefficients in a VAR model including both inflation and inflation expectations to estimate the rational and non-rational components of inflation expectations shocks. A positive shock is found to have deflationary and contractionary effects on the US economy, which is inconsistent with the NKPC. Ascari et al. (2023) instead consider

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[1] The variable ordering with inflation expectations first reflects the time when survey participants submit their responses, which is usually in the middle of the month at a monthly frequency, or in the second month of the quarter at a quarterly frequency. Since agents making a forecast at time t do not know the time t realisation of economic variables, this ordering is common practice to identify inflation expectations shocks in a VAR framework.

the macroeconomic effects of short-term inflation expectations shocks to assess departures from rationality and find evidence for an asymmetric transmission mechanism. Using a VAR model with sign restrictions, they report that shocks increasing inflation expectations affect real macroeconomic variables more strongly than those decreasing them.

Despite theory highlighting the importance of real interest rates as a determinant of economic activity (Mishkin, 1981), there are relatively few empirical studies on this topic. Taylor (1999) summarises some of the early empirical evidence and concludes that the link between the real interest rate and macroeconomic aggregates, especially economic growth and investment, is surprisingly weak. This has been challenged by later studies. For instance, King and Watson (1996) report that in the US real interest rates are countercyclical and lead the cycle. Neumeyer and Perri (2005), instead, assess the contribution of the real interest rate to output volatility in emerging and developed economies and find that they are countercyclical and lead the cycle in the former, but are a-cyclical and lag the cycle in the latter. Uribe and Yue (2006) estimate a VAR model to assess the effect of the world real interest rate on emerging market fundamentals and report a strong negative correlation between real interest rates and economic activity.

Recently, a novel approach to representing shocks has been developed by Inoue and Rossi (2021), who identify functional monetary shocks as shifts in the entire term structure of nominal yields around monetary policy announcements. They assess the macroeconomic impact of these functional shocks and find that differences in their shape between the short and the long end significantly affect the responses of output and inflation. Monetary policy seems to transmit information to the economy not only about short-term interest rates but also about their medium- and long-term path, which is particularly relevant during the zero lower bound period. Their method can be applied to different types of shocks (both inflation expectations and *ex-ante* real interest rate shocks in the present case) and is outlined in the following section.

3. Empirical Framework

3.1 The Term Structure of Inflation Expectations and Real Interest Rates
Following Inoue and Rossi (2021), we represent inflation expectations shocks as shifts in a function. For this purpose, first a term structure has to be computed, where inflation expectations are a function of short-, medium- and long-term maturities. This can be done using

the standard term structure model by Nelson and Siegel (1987) which uses three factors (level, slope and curvature) to summarise the shape of the yield curve – the same approach can be applied to create a curve of inflation expectations with horizons ranging from 3 to 120 months. The standard Nelson and Siegel (1987) model (henceforth NS) is the following:

$$y_t(\tau) = \beta_{1,t} + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\right)\beta_{2,t} + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right)\beta_{3,t} + \varepsilon_t \qquad (1)$$

where $y_t(\tau)$ is the yield of a bond with τ months to maturity, $\beta_{1,t}$, $\beta_{2,t}$ and $\beta_{3,t}$ are the time-varying level, slope and curvature factors which are all latent, λ is a parameter which characterises the factor loadings for the maturities and ε_t is a measurement error. The assumption for the inflation expectations term structure is that it has similar smoothness and persistence properties to the yield curve (Aruoba, 2020). Hence, one can model it as follows:

$$\pi_t^e(\tau) = \beta_{1,t} + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\right)\beta_{2,t} + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right)\beta_{3,t} + \varepsilon_t \qquad (2)$$

where $\pi_t^e(\tau)$ is the τ-month inflation expectation in month t for month $t + \tau$. As can be seen, in this context inflation expectations are functions of τ. The level factor $\beta_{1,t}$ represents long-term inflation expectations, the slope factor $\beta_{2,t}$ captures differences between long-term and short-term inflation expectations, and the curvature factor $\beta_{3,t}$ measures higher or lower expectations in the medium term relative to short- and long-term ones. The three latent factors $\beta_{1,t}$, $\beta_{2,t}$ and $\beta_{3,t}$ are assumed to follow independent AR(3) processes and are represented in a state-space model following the dynamic approach in Diebold et al. (2006). The estimation is carried out using the Kalman filter.[2] This term structure representation is particularly useful, since one can construct it using survey data of inflation expectations, which are known to be more informative for macroeconomic indicators than other measures (Faust and Wright, 2013).

The inflation expectations curve can then be used to construct an *ex-ante* real interest rate yield curve, where the *ex-ante* real interest rate r_t is defined as the difference between the nominal yield and inflation expectations (Fisher, 1930) as in the following equation:

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[2] Further details regarding the model can be found in Appendix A.

$$r_t(\tau) = y_t(\tau) - \pi_t^e(\tau) \tag{3}$$

where $r_t(\tau)$ is the *ex-ante* real interest rate curve. The nominal yield curve $y_t(\tau)$ is estimated with the standard Nelson-Siegel specification using monthly averages of nominal yields at all maturities. This approach captures the monetary policy stance over a wider time horizon and therefore provides valuable information during both conventional and unconventional periods (Holsten et al., 2017).

3.2 Functional Shocks and the Functional VARX

After computing the term structures of inflation expectations and *ex-ante* real interest rates, one can use them to estimate functional shocks, which are defined as exogenous shifts in the entire term structure. Note that the functional shocks obtained from the *ex-ante* real interest rate term structure combine both expectational and monetary policy shocks captured by the nominal yield curve at all time horizons. Thus, they are highly informative about the monetary policy stance and its credibility at different time horizons.

To assess the macroeconomic effects of the estimated functional shocks, we use the following Vector Autoregressive Model with exogenous variables (VARX):

$$Y_t = \mu + A(L)Y_t + \Theta X_t + U_t \tag{4}$$

where Y_t is an $n \times 1$ vector of endogenous macroeconomic variables, in our case inflation (π_t), output (g_t) and the policy rate (i_t), X_t is a $m \times 1$ vector of exogenous variables which contains the functional inflation expectations and *ex-ante* real interest rate shocks, $A(L) = A_1 L + \ldots + A_p L^p$, A_j and Θ are the $n \times n$ and $n \times m$ matrices of coefficients, U_t are the reduced-form residuals, and μ is a constant. The lag order is determined using the Bayesian-Schwarz information criterion (BIC). The functional shocks $X_t = \Delta\beta_{i,t}^{\pi^e}, \Delta\beta_{i,t}^r, \quad i = 1,2,3$ are represented as the simultaneous change in level ($\beta_{1,t}$), slope ($\beta_{2,t}$) and curvature ($\beta_{2,t}$) of the term structure of inflation expectations (π^e) and of the *ex-ante* real interest rate (r). The macroeconomic effects of the functional shocks are given by:

$$\sum_{i=1}^{3} \Theta_{i,h}^{(j)} \Delta\beta_{i,t}^j, \quad j = \pi^e, r \tag{5}$$

For identification purposes we impose a set of zero and sign restrictions which are common to identify inflation expectations shocks (Neri, 2021; Ascari et al., 2023). More specifically, we assume the following:

(i) Inflation, output and the policy rate are not contemporaneously affected by inflation expectations and *ex-ante* real interest rate shocks.[3]

(ii) A negative shock to inflation expectations has a negative impact on inflation.

(iii) There is no restriction on the response of output to an inflation expectations shock, which allows us to distinguish it from a standard supply shock.

(iv) A negative *ex-ante* real interest rate shock has a positive effect on output.

(v) Inflation and output respond positively to a negative (expansionary) monetary policy shock.

(vi) There is no restriction for the response of inflation to an *ex-ante* real interest rate shock, which allows us to distinguish it from a standard monetary policy shock.

(vii) There is no sign restriction on the response of the policy rate to either inflation expectations or *ex-ante* real interest rate shocks.

The above restrictions allow us to distinguish between *ex-ante* real interest rate shocks, which contain important information about the yield curve, and standard monetary policy ones. We use the algorithm by Arias et al. (2018) to select the appropriate model given the zero and sign restrictions. In line with Inoue and Rossi (2021) we use fourth-order polynomials to deal with excessive variations in the estimates of the model given by (4).

3.3 Nonlinear Functional Local Projections

Next we allow for the possibility that the macroeconomic effects of functional inflation expectations and *ex-ante* real interest rate shocks might be nonlinear and depend on the credibility of the central bank. For this purpose, we use functional local projections as in Jordà (2005). His approach has some notable advantages over the VAR methodology since it is less likely to suffer from mis-specification of the data generating process (DGP) and, most importantly, it can accommodate more flexible specifications including nonlinear ones. More specifically, we estimate a Functional Local Projections model (FLP) which is state-dependent and therefore able to account for nonlinearities:

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[3] This is partly due to the timing of inflation expectations surveys which are generally carried out towards the middle or end of the month and therefore are less likely to influence macroeconomic aggregates within the same month.

$$Y_{t+h} = \mu_{h,t} + A_{h,t}(L)Y_{t-1} + \Theta_{i,h,t}^{(j)}X_t^d + e_{h,t+h} \tag{6}$$

where all variables are defined as before. The coefficients $\Theta_{i,h,t}^{(j)}$ are the responses of the endogenous variables at time $(t+h)$ to a functional shock $\Delta\beta_{i,t}^j$, $i = 1,2,3$; $j = \pi^e, r$ originating at time t where $h = 1,2,...H$ is the horizon of the response. The parameters are now time-varying and state-dependent, where d_t is a dummy variable which indicates the state at the time when the shock occurs. In particular, we consider different degrees of central bank credibility and define a state of high credibility with well-anchored expectations, where the dummy variable d_t takes the value of 0 if inflation expectations are in a 100 basis point range above or below the inflation target, and a state of low credibility, where inflation expectations are outside these bands and d_t takes the value of 1.[4] For example, if the inflation target is 2%, then inflation expectations which are below 1% or above 3% indicate a de-anchoring of expectations and therefore a state of low central bank credibility. We set the maximum response horizon $H = 12$.

4. Data and Empirical Results

4.1 Data Description

We use monthly data for the US, the UK and the euro area (EA); the choice of countries is determined by the availability of inflation expectations survey data at monthly frequency. The sample starts in January 1998 and ends in May 2023. For the US, we obtain the term structure data for inflation expectations and the *ex-ante* real interest rate from the Aruoba Term Structure of Inflation Expectations (ATSIX) dataset available from the Federal Reserve Bank of Philadelphia website.[5] For the other countries in our sample, we follow the approach by Aruoba (2020) outlined in Section 3.1 to estimate the term structures. Appendix B describes the sources for the inflation expectations survey data as well as for the UK and EU nominal yield curve data used to construct the *ex-ante* real interest rates. The Consumer Price Index (CPI) data are obtained from the Organisation for Economic Co-operation and Development (OECD)

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[4] Alternatively, we could have defined the states in a way that differentiates between conventional and unconventional monetary policy periods, in which case d_t would take the value of 0 during conventional times, i.e. when $i_t > 0.25$, and the value of 1 during the zero lower bound period, when $i_t \leq 0.25$. However, since the overall state of central bank credibility is known to affect the transmission of shocks to inflation (Anderl and Caporale, 2023), it seems appropriate to base state-dependence on credibility in the context of expectations shocks. Incidentally, the high credibility regimes seem to largely coincide with conventional monetary policy times.

[5] https://www.philadelphiafed.org/surveys-and-data/real-time-data-research/atsix

database for all countries; inflation is then calculated as the annual growth rate. The output series are real normalised GDP obtained from the OECD Monthly Economic Indicators directorate; their annual percentage change is then computed. The central bank policy rates are taken from the Bank for International Settlements (BIS) Statistics database.

Figure 1. Inflation expectations and *ex-ante* real interest rates over time

Panel A. Inflation expectations	Panel B. *Ex-ante* real interest rates
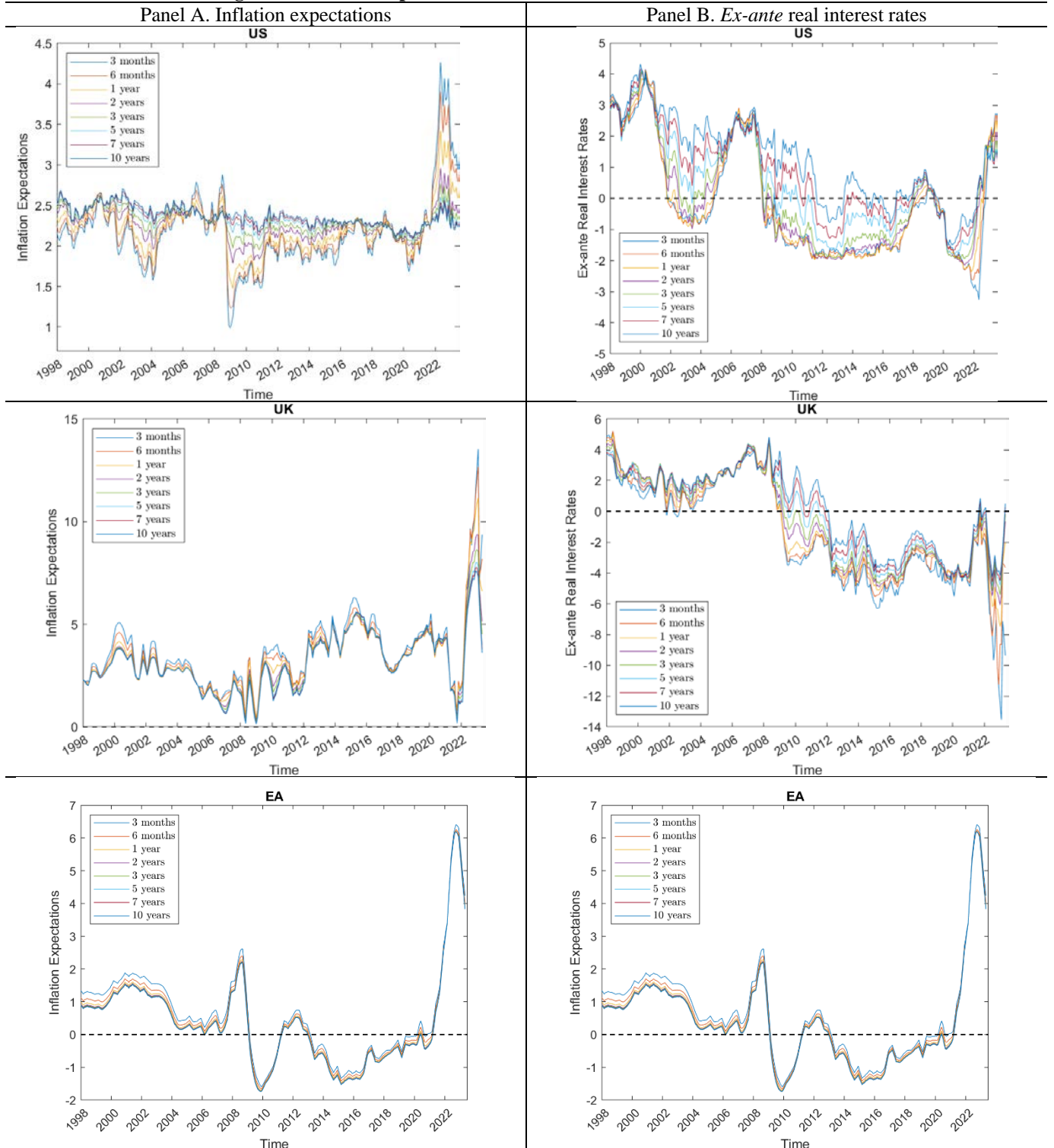
Notes: Inflation expectations and *ex-ante* real interest rates for different maturities over time.

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Figure 1 displays inflation expectations (Panel A) and *ex-ante* real interest rates (Panel B) for all countries over the period from January 1998 to May 2023 for different maturities ranging from 3 months to 10 years. One can observe large swings in the former after the global financial crisis (GFC) of 2007-8 and the recent move away from the zero lower bound, especially at short maturities. Further, inflation expectations turned negative in the EU during several periods, for instance after the GFC and between 2013 and 2020. Large differences between maturities (and during the zero lower bound period in the US and the UK) are also noticeable in the case of *ex-ante* real interest rates. For this reason functional shocks are estimated next as previously explained.

4.2 Functional Shocks
Figure 2 shows functional shocks to inflation expectations (Panel A) and *ex-ante* real interest rates respectively during periods characterised by high central bank credibility. Concerning the former, in a lot of instances one can see differences in terms of term structure shifts between the short and the long end. For instance, in the UK short-term expectations changed more in August 2006 relative to long-term ones, while the opposite is true of June 2021. Moreover, one can observe an inverted term structure during some periods. For instance, in October 2002 long-term inflation expectations in the US were anchored more relative to short-term ones, while the opposite holds for August 2006. An inverted yield curve can also be seen at times in the case of *ex-ante* real interest rate shocks, for instance for the US in March 2022, for the UK in November 1998 and for the euro area in September 2021.

Figure 3 displays the functional shocks during periods of low central bank credibility. Again there are noticeable differences between different maturities. For instance, in the case of the inflation expectations shocks in September 2021 in the US or July 2020 in the euro area there is hardly any shift at the long end, whilst sizeable shifts occur at the short one (see Panel A). By contrast, medium- and long-term expectations shifted significantly in February 2020 in the US and in December 2019 in the UK, whilst short-term expectations hardly changed. This again supports using functional instead of scalar shocks to provide a more comprehensive description of changes in inflation expectations. Similarly, in the case of the *ex-ante* real interest rate shocks (see Panel B) large shifts and even inversions occurred at the medium- to long-term, while there were almost no changes at the short end, especially in the euro area.

Figure 2. Functional shocks in high credibility times

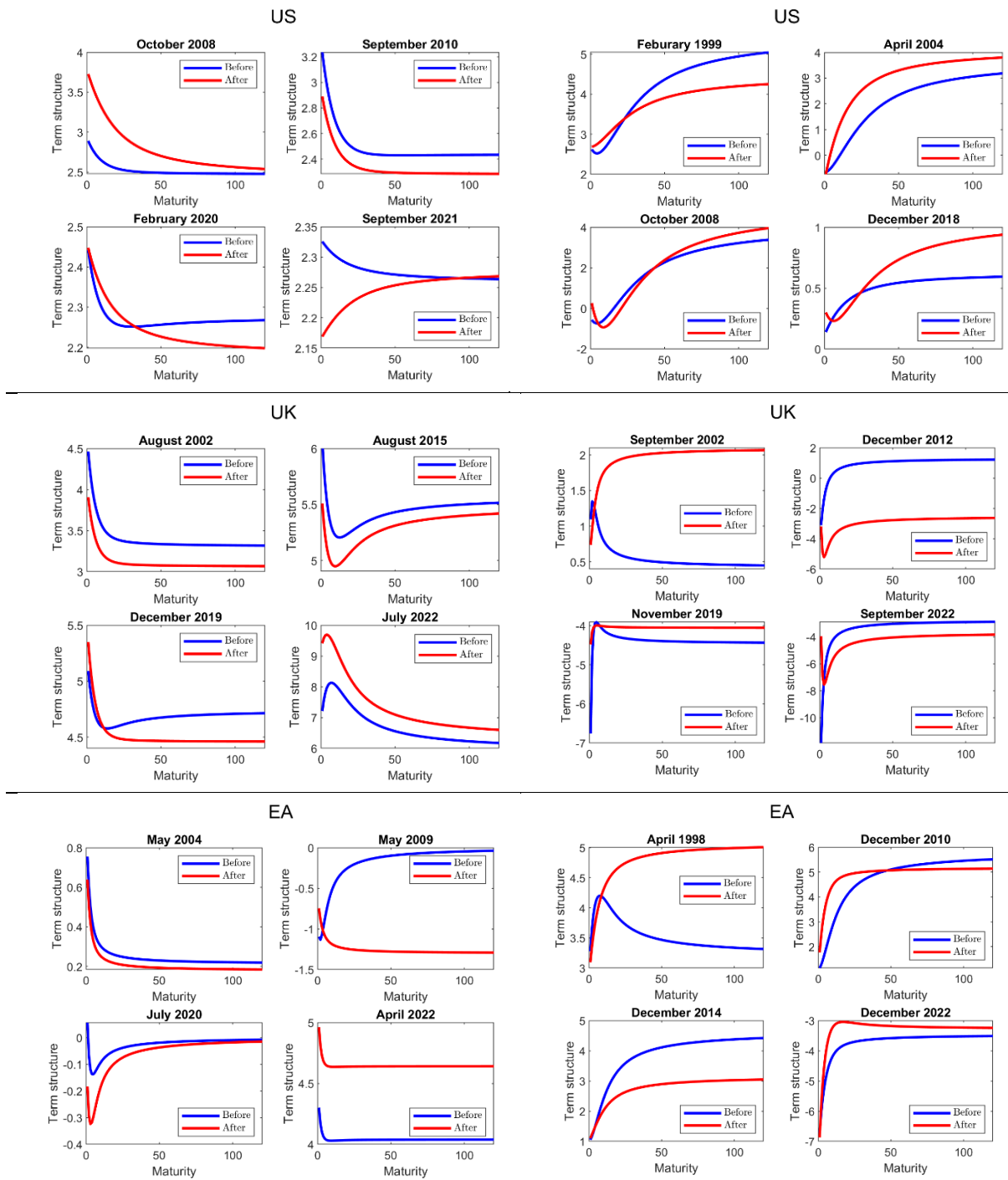| Panel A. Inflation expectations for selected shock dates	Panel B. *Ex-ante* real interest rates for selected shock dates
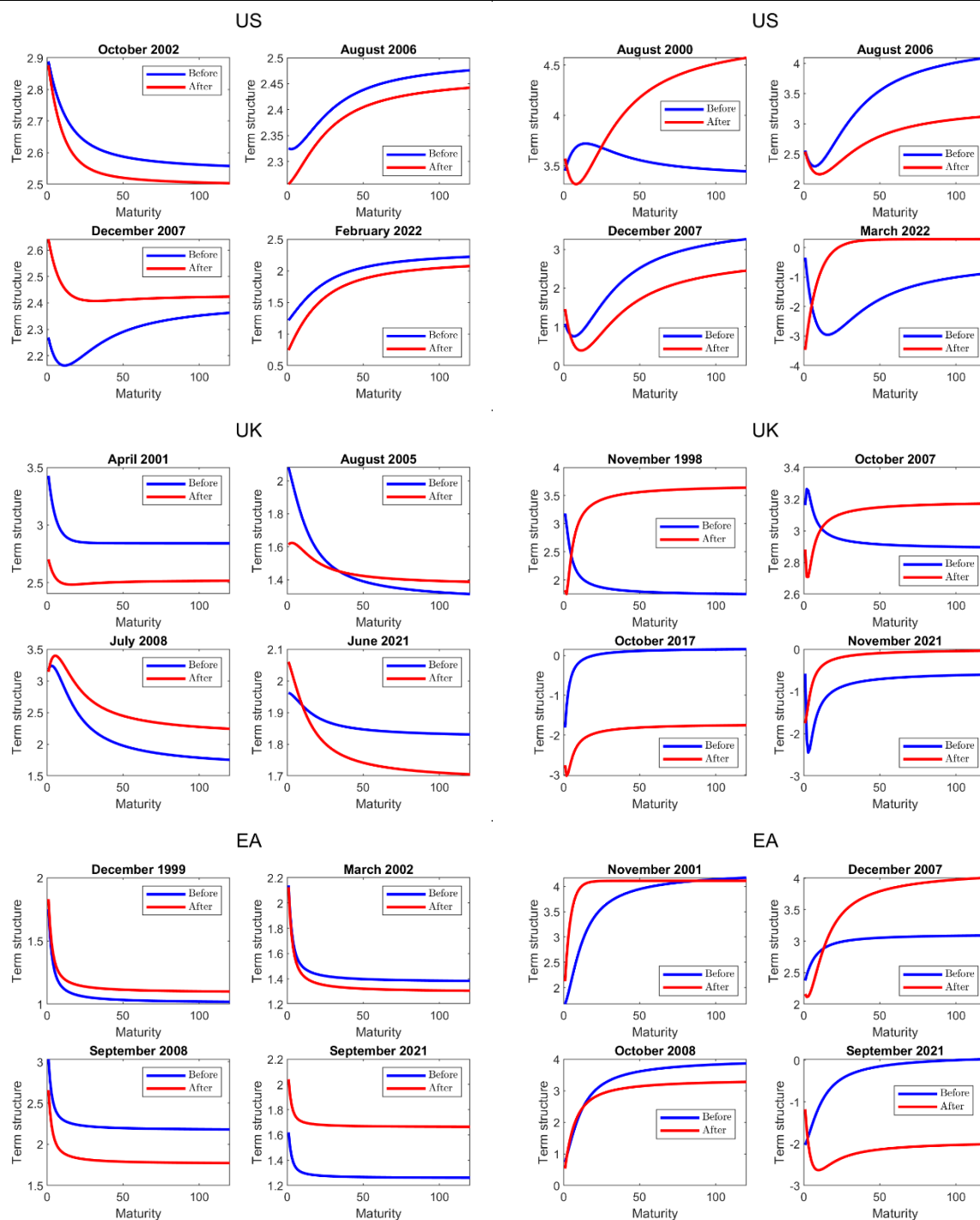
Notes: Representative examples of functional shocks.

Figure 3. Functional shocks in low credibility times

Panel A. Inflation expectations for selected shocks dates	Panel B. *Ex-ante* real interest rates for selected shock dates

Notes: Representative examples of functional shocks.

Figure 4. Functional shocks over time

| Panel A. Inflation expectations shocks | Panel B. *Ex-ante* real interest rate shocks |
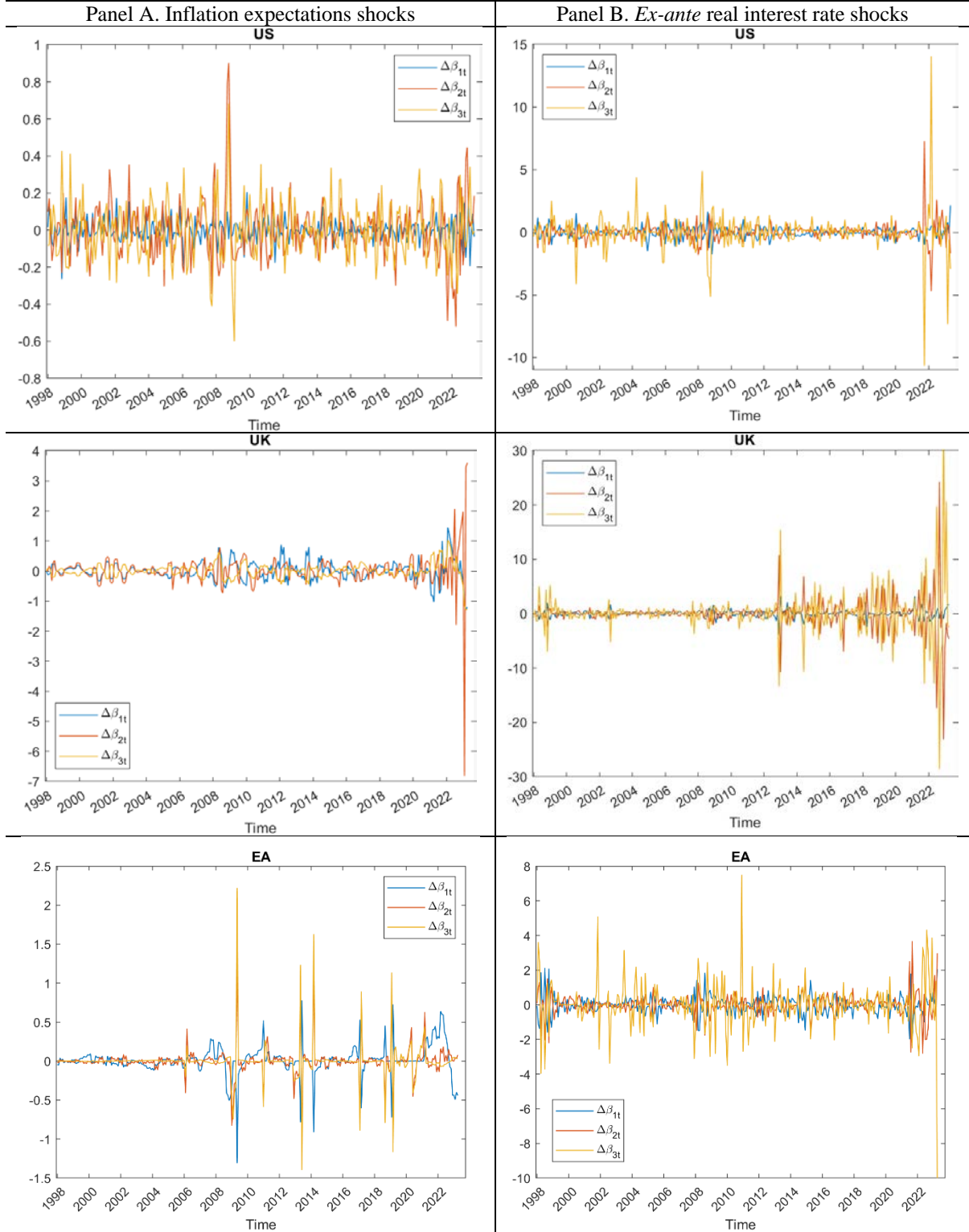
Notes: The components of the functional shocks over time.

Figure 4 displays the evolution of the functional shocks over time. Large swings can be observed during key periods, including those corresponding to the GFC and the move away from the zero lower bound. It is apparent that the contribution of each term structure parameter to the overall functional shock changes over time. In most instances functional shocks are driven by slope changes ($\Delta\beta_{2t}$) and curvature changes ($\Delta\beta_{3t}$). The magnitude of both $\Delta\beta_{2t}$ and $\Delta\beta_{3t}$ became significantly larger over time. The level shocks ($\Delta\beta_{1t}$) seem to be largely constant over time.

4.3 The Macroeconomic Effects of Functional Shocks

To assess the macroeconomic effects of the functional shocks to inflation expectations and *ex-ante* real interest rates, we estimate a Functional VARX model where these shocks are entered as exogenous variables. Figures 5 and 6 display the responses of inflation, output and the policy rate to inflation expectations and real interest rate shocks for the US. Figure 5 shows the results when the US economy is in a state characterised by anchored inflation expectations and high central bank credibility. It is noteworthy that inflation responds more strongly to inflation expectations shocks (Panel A), while *ex-ante* real interest rate shocks have a stronger impact on output (Panel B). It seems that a shock which increases inflation expectations across all maturities (represented by an upward shift of the inflation expectations term structure) has a positive effect on inflation, while a downward shift in inflation expectations affects inflation negatively, which is consistent with theory. An increase in the *ex-ante* real interest rate is expected to have a negative effect on output, but this happens only in some instances. A negative *ex-ante* real interest rate shock of similar size is also found to have different effects on output. In August 2006, for instance, the positive response of output occurs only with a substantial lag after being negative on impact. By contrast, in December 2007, the response is positive on impact. Further, it is much larger in cases where the term structure does not shift equally at the short and the long end, or there is even an inverted yield curve.
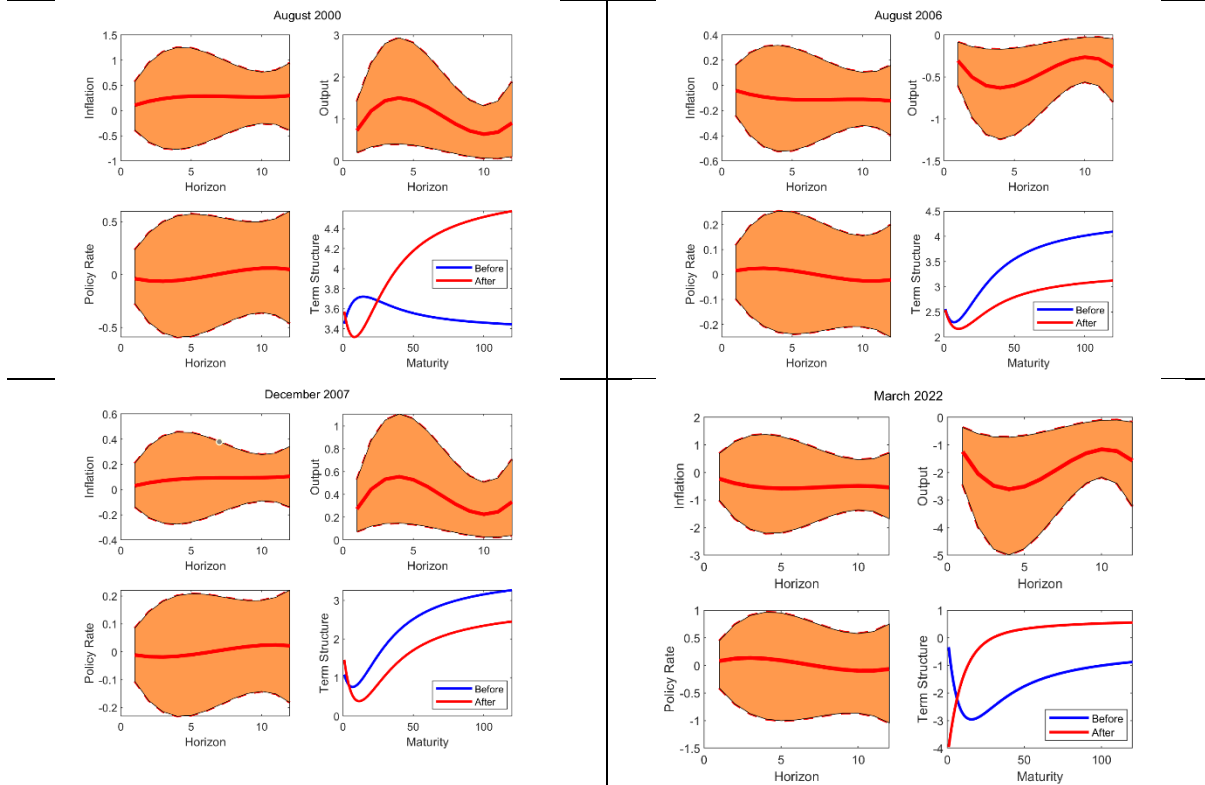
Figure 5. US IRFs in high credibility times
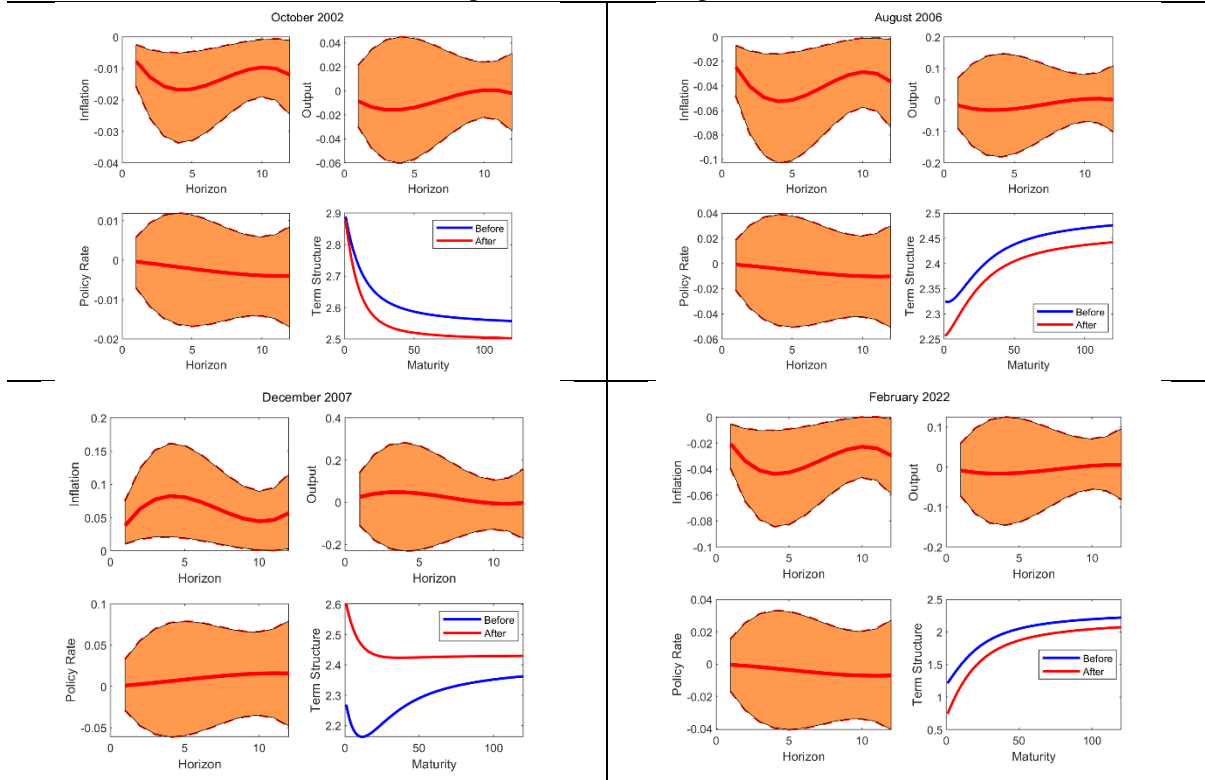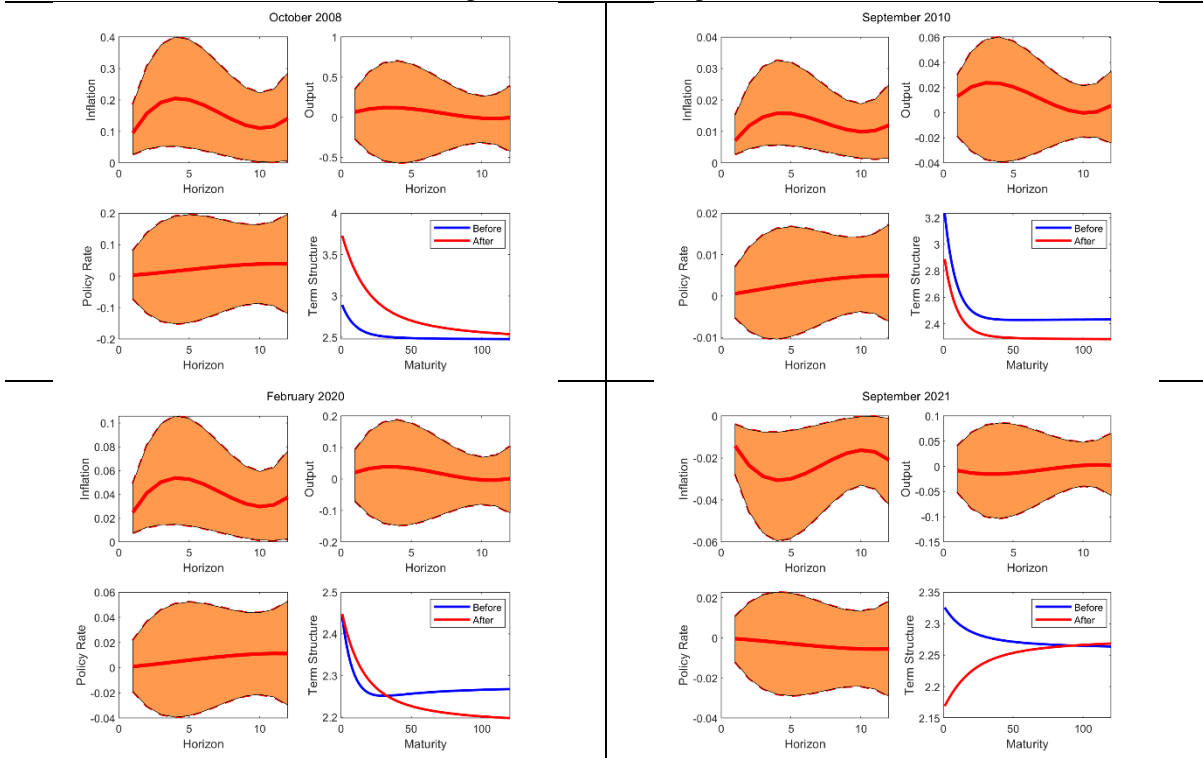
Panel A. Responses to inflation expectations shocks

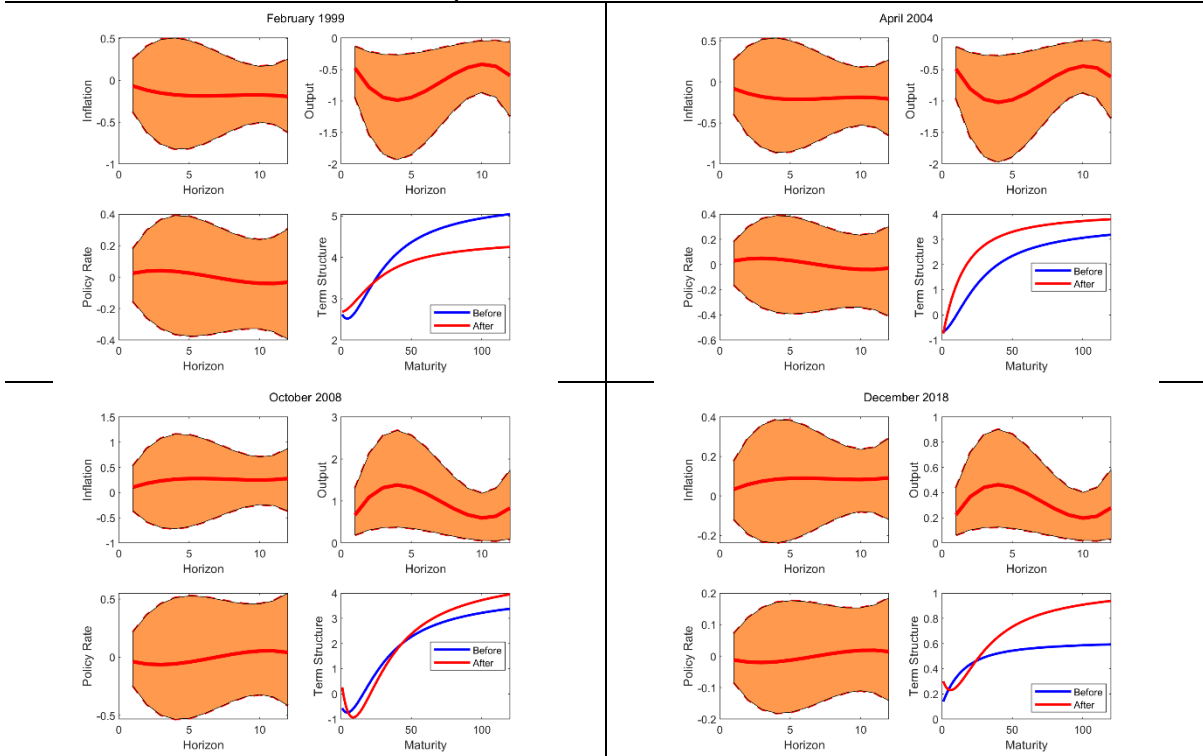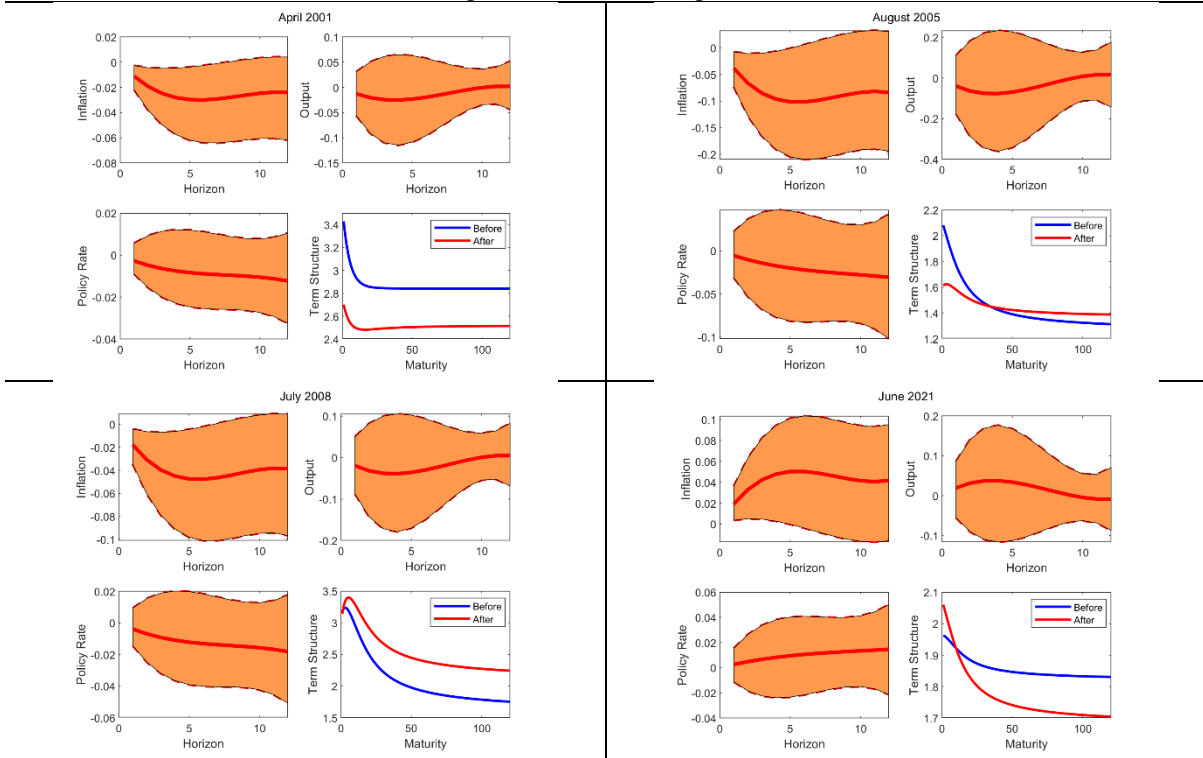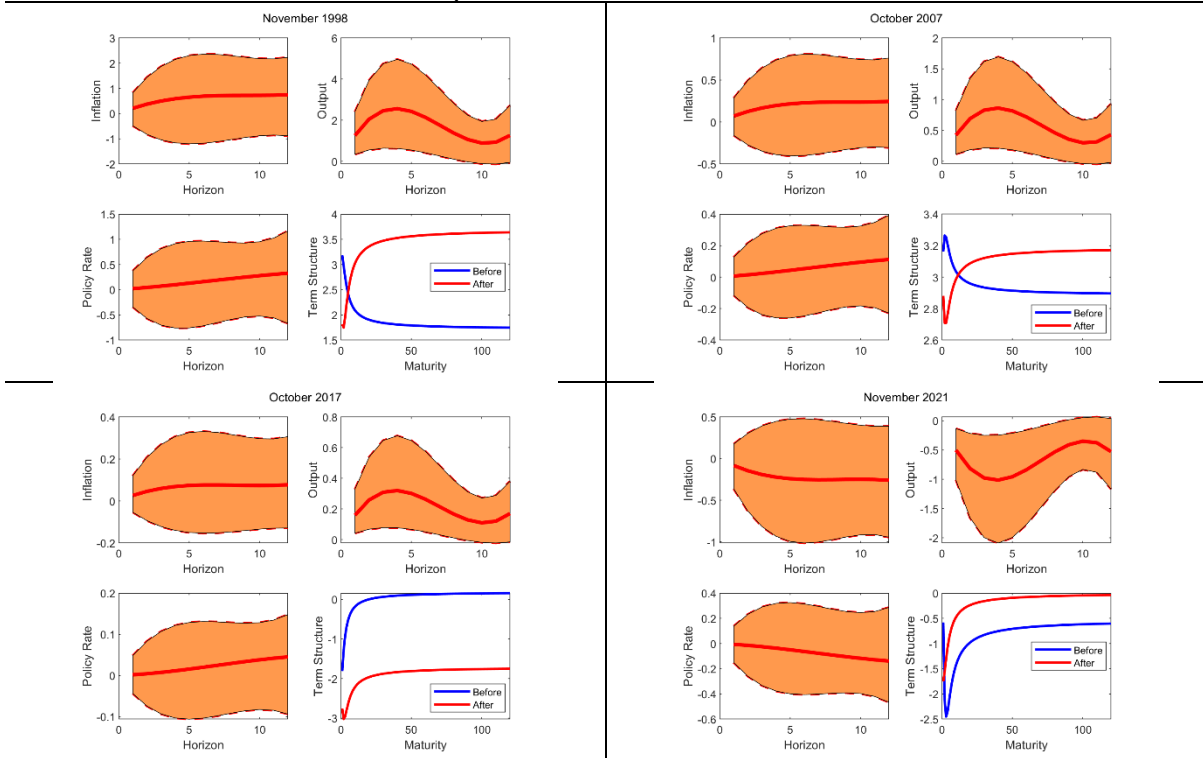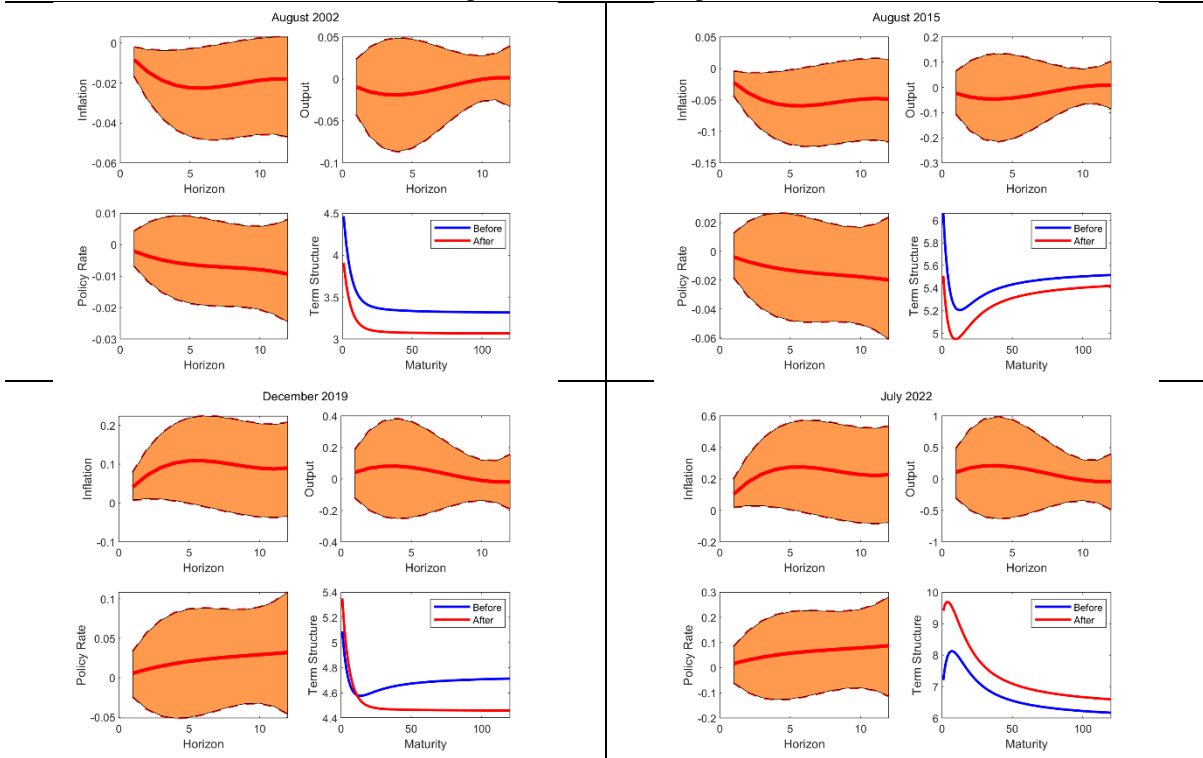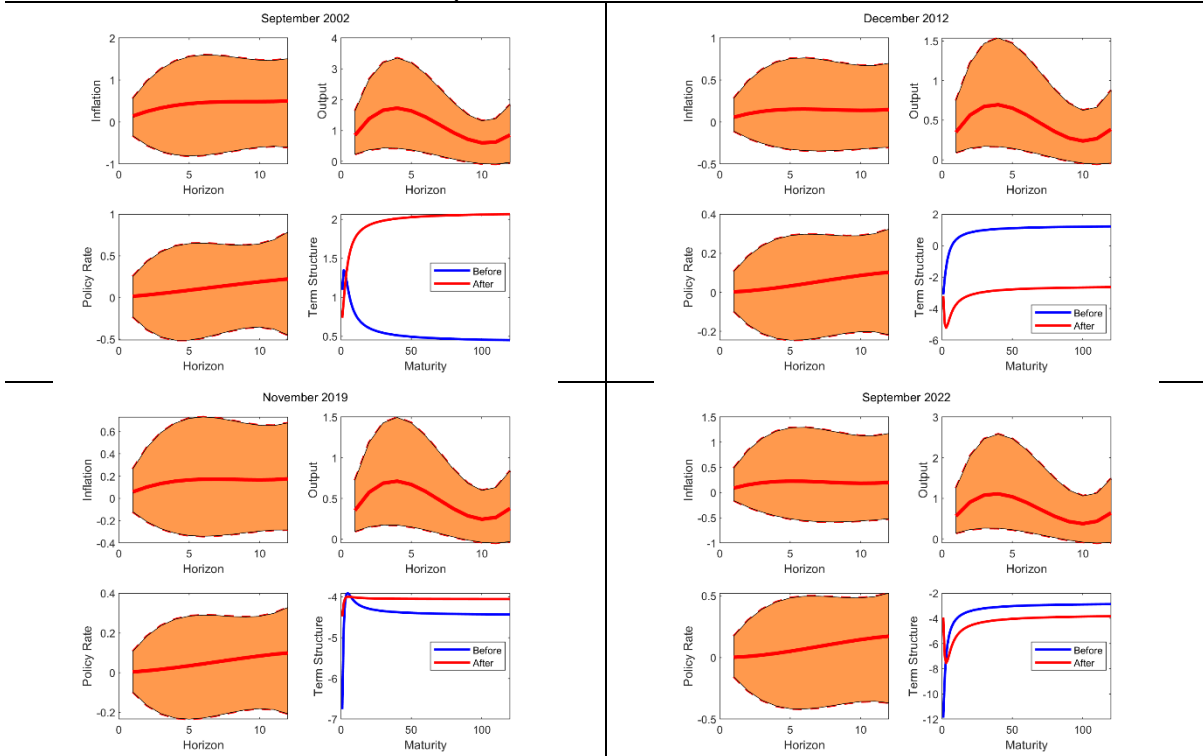Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Responses of output, inflation and the policy rate to inflation expectations and *ex-ante* real interest rate shocks during representative high credibility times.

Figure 6. US IRFs in low credibility times

Panel A. Responses to inflation expectations shocks

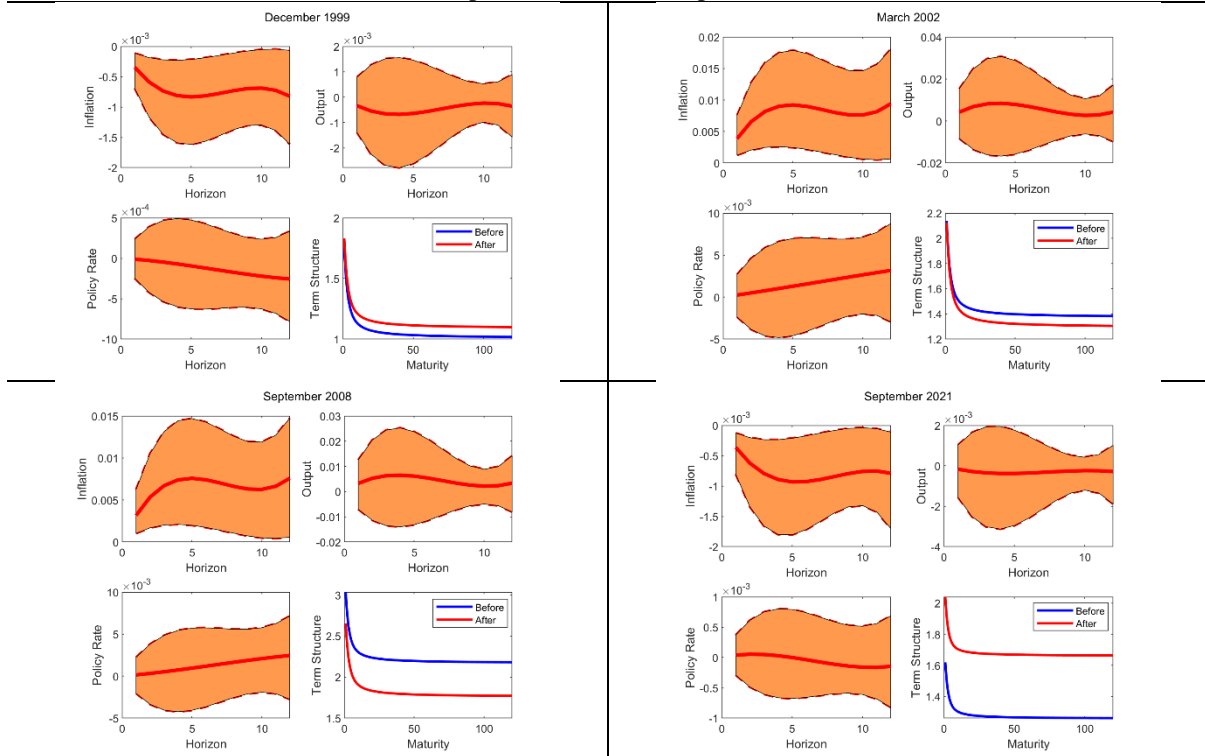### Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Responses of output, inflation and the policy rate to inflation expectations and *ex-ante* real interest rate shocks during representative low credibility times.

Figure 7. UK IRFs in high credibility times

Panel A. Responses to inflation expectations shocks

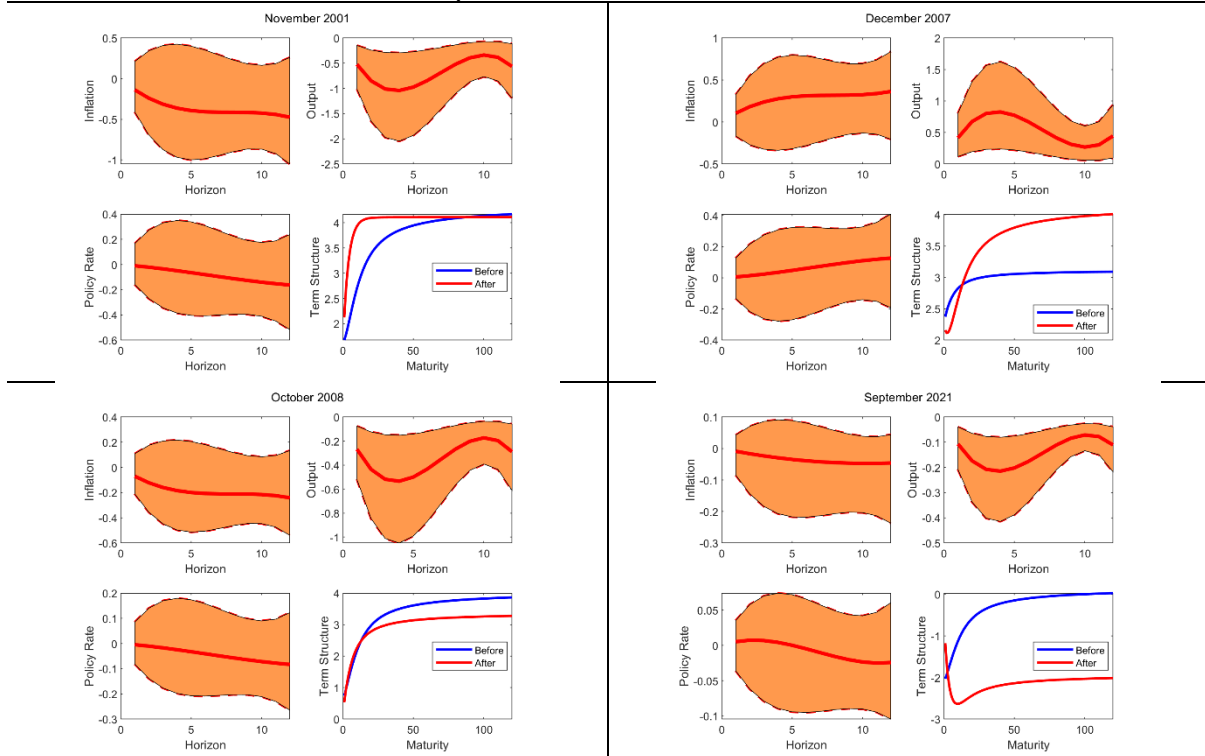
Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Responses of output, inflation and the policy rate to inflation expectations and *ex-ante* real interest rate shocks during representative high credibility times.

Figure 8. UK IRFs in low credibility times

Panel A. Responses to inflation expectations shocks

Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Responses of output, inflation and the policy rate to inflation expectations and *ex-ante* real interest rate shocks during representative low credibility times.

Figure 9. Euro area IRFs in high credibility times
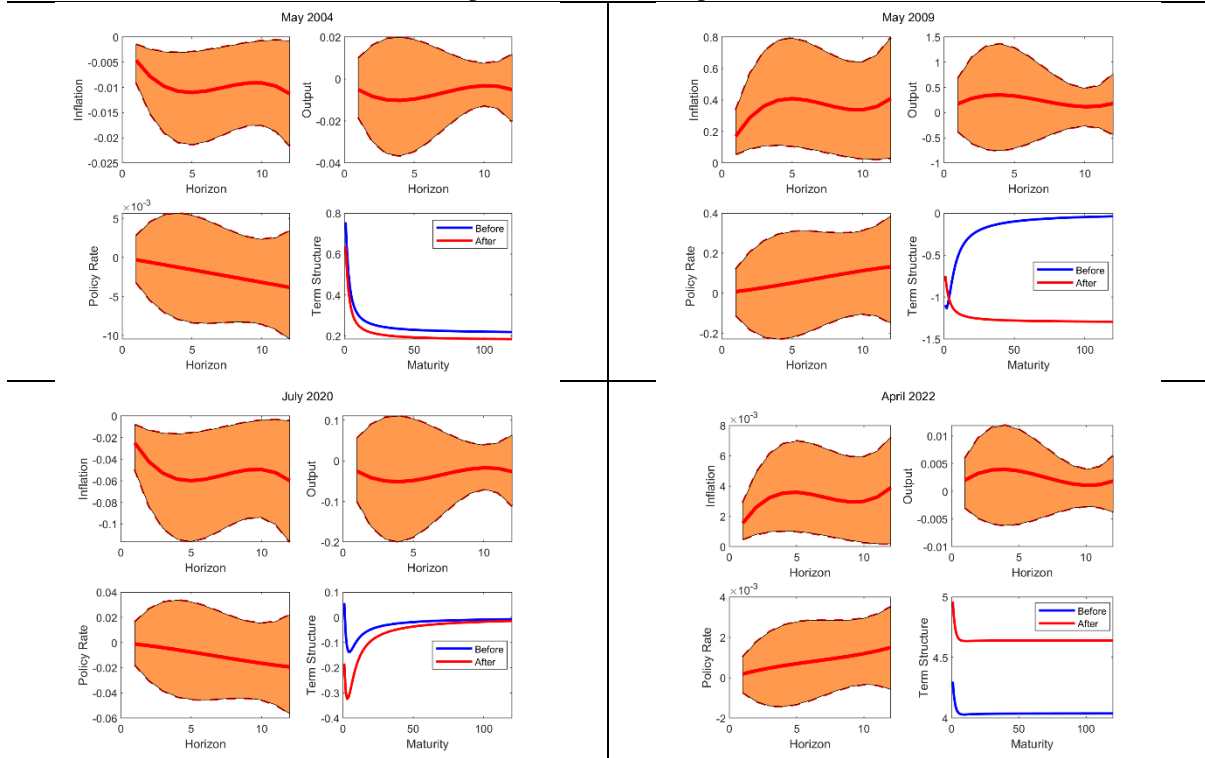
Panel A. Responses to inflation expectations shocks

Panel B. Responses to *ex-ante* real interest rate shocks
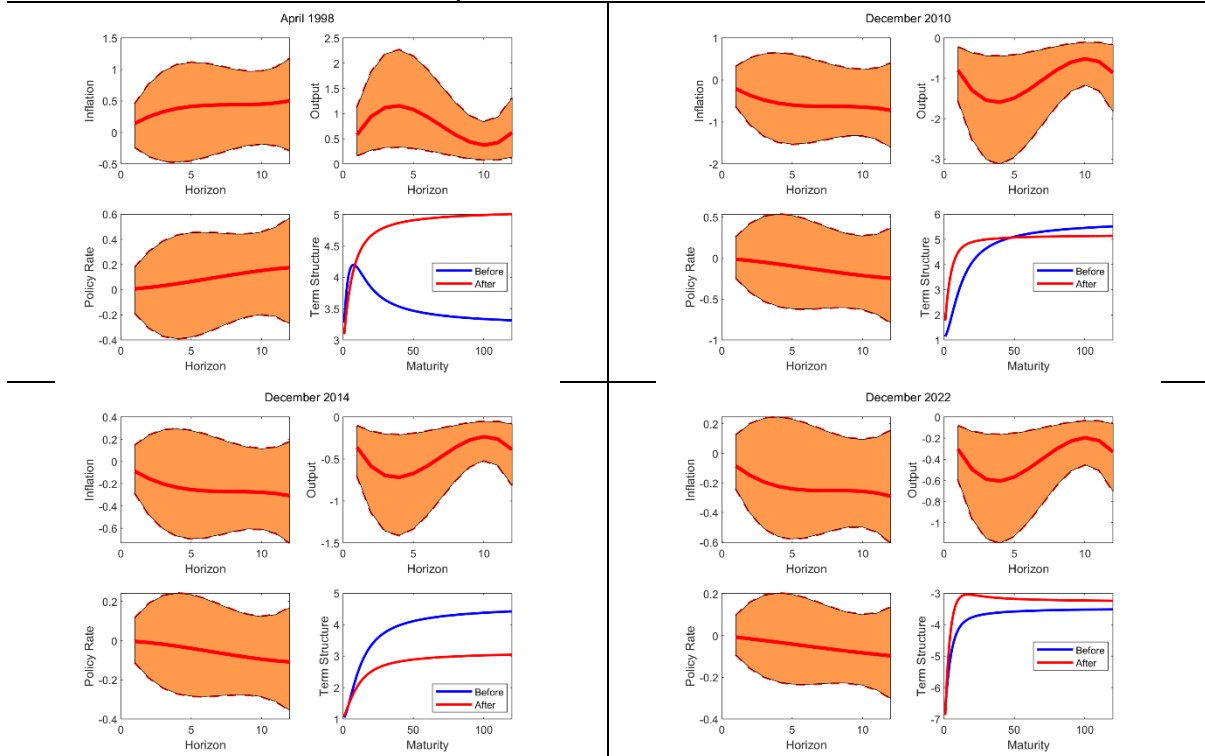

Notes: Responses of output, inflation and the policy rate to inflation expectations and *ex-ante* real interest rate shocks during representative high credibility times.

Figure 10. Euro area IRFs in low credibility times

Panel A. Responses to inflation expectations shocks

Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Responses of output, inflation and the policy rate to inflation expectations and *ex-ante* real interest rate shocks during representative low credibility times.

Figure 6 plots the responses to inflation expectations (Panel A) and *ex-ante* real interest rate (Panel B) shocks for selected dates when central bank credibility in the US was low. In some cases inflation increases in response to a shock which decreases inflation expectations, and the output response to positive *ex-ante* real interest rate shocks is positive, in both cases in contrast to theory. As Inoue and Rossi (2021) point out, identical monetary policy shocks in different time periods can have different effects depending on how short-term and long-term expectations behave. *Ex-ante* real interest rates, which contain important information about both inflation expectations and nominal yields at different maturities, seem to play an important role in the monetary policy transmission mechanism, especially through changes in the long end of the term structure, which the standard policy rate does not capture. Functional shocks also contain information about the long-term outlook regarding monetary policy and economic conditions in general, which can help to explain the sign of the output response.

The results for the UK during periods of high central bank credibility are shown in Figure 7. In this case, the inflation response to inflation expectations shocks is very small. Instead, the output response to an *ex-ante* real interest rate shock is large and, unlike in the US, it has the expected sign. Figure 8 displays the corresponding results for low credibility times. The responses of inflation and output to inflation expectations and *ex-ante* real interest rate shocks now have the expected signs. Figure 9 and 10 report the results for the euro area during high and low credibility times, respectively. Surprisingly, inflation responds negatively (positively) to shocks which increase (decrease) inflation expectations when credibility is high (but not when it is low). The output response to *ex-ante* real interest rate shocks is also the opposite to what one would expect, regardless of the degree of central bank credibility.

4.4 Nonlinear Functional Shocks
Given the observed differences between high and low central bank credibility periods, next we estimate a nonlinear threshold FLP model to capture regime dependence. Figures 13, 14 and 15 show the impulse responses to inflation expectations (Panel A) and *ex-ante* real interest shocks respectively for selected dates in the high credibility state (state 0, left-hand side) and the low credibility one (state 1, right-hand side) for the US, the UK and euro area in turn.

In general, inflation, output and the policy rate increase in response to downward shifts in the inflation expectations term structure (Panel A). In cases where there are bigger increases at the short end relative to the long end of the term structure, inflation and output move in the same

direction, while if more sizeable decreases occur at the long end decreases compared to the short one, inflation and output tend to move in opposite directions. This suggests that shocks resulting mainly from changes in long-term expectations resemble more closely the dynamics of supply shocks, while those which predominantly reflect changes in short-term expectations have similar effects to demand shocks. This holds true especially in state 1, i.e. when central bank credibility is low. Changes in the *ex-ante* real interest rate term structure which have different effects for different maturities generate larger responses in inflation and output (Panel B). In cases characterised by a decrease (increase) at the short end and an increase (decrease) at the long end, inflation, output and the policy rate tend to fall (rise). This indicates that a steepening (inversion) of the term structure has a deflationary (inflationary) and recessionary (expansionary) effect on the economy. This is especially the case in state 0, i.e. when central bank credibility is high.

Figure 13. US IRFs in the Time-varying FLP framework

Panel A. Responses to inflation expectations shocks
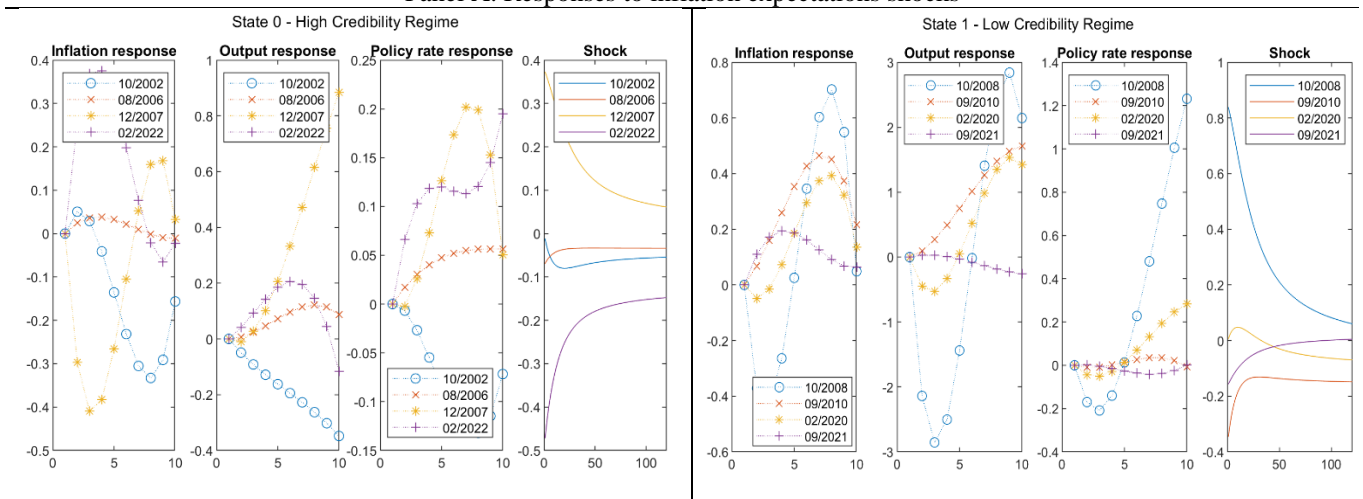
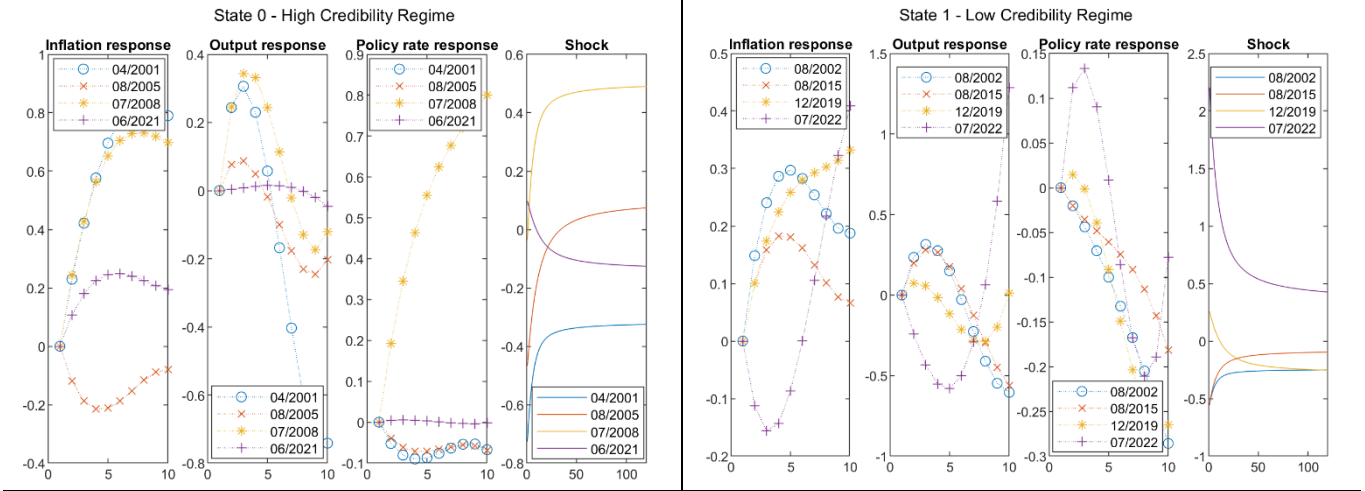Panel B. Responses to *ex-ante* real interest rate shocks
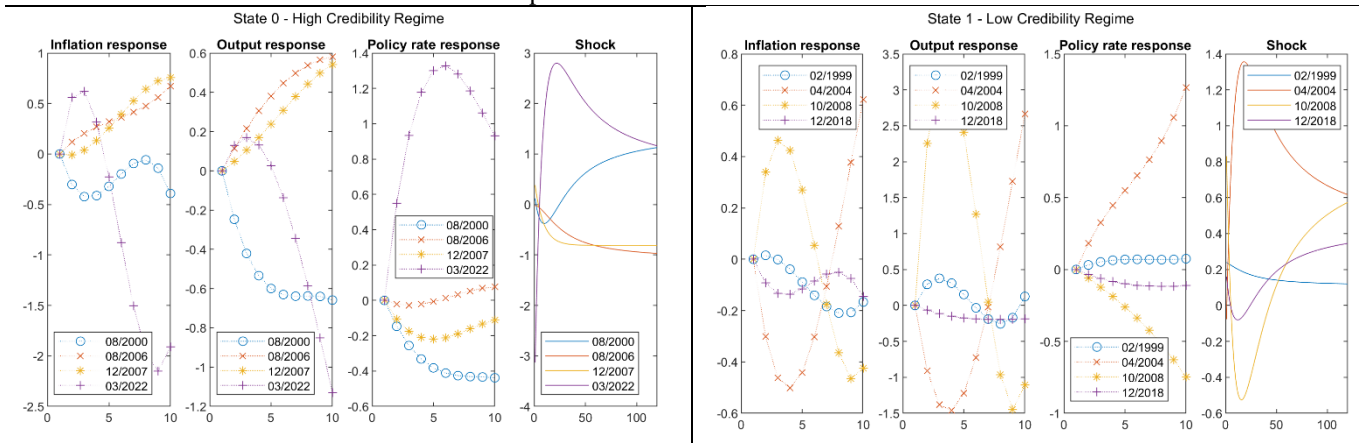
Notes: Impulse response functions of output, inflation and the policy rate in the low and high credibility regimes.
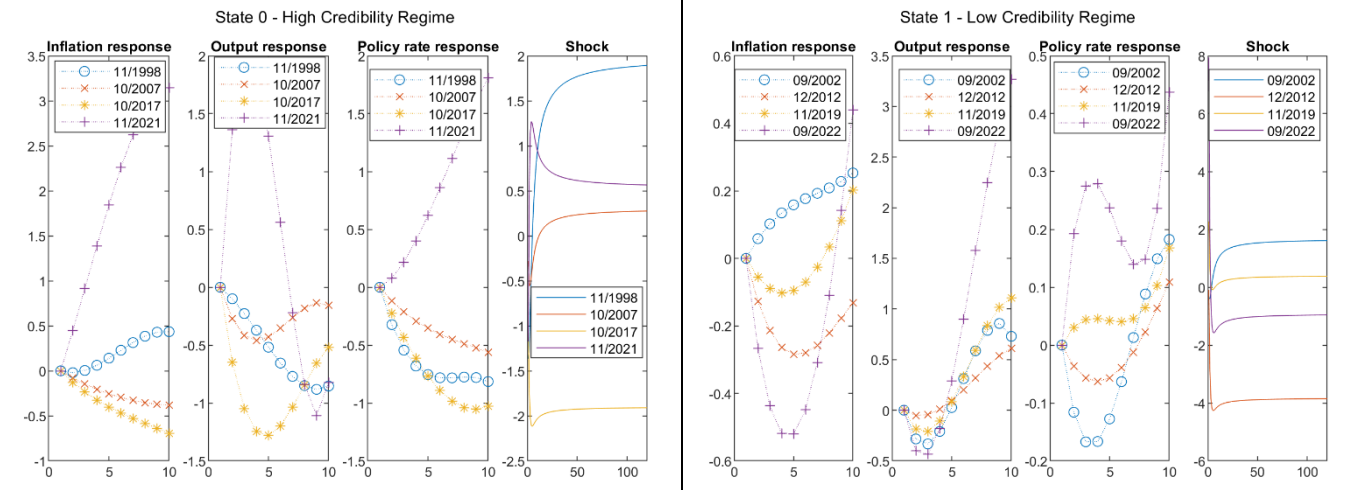
Figure 14. UK IRFs in the Time-varying FLP framework

Panel A. Responses to inflation expectations shocks

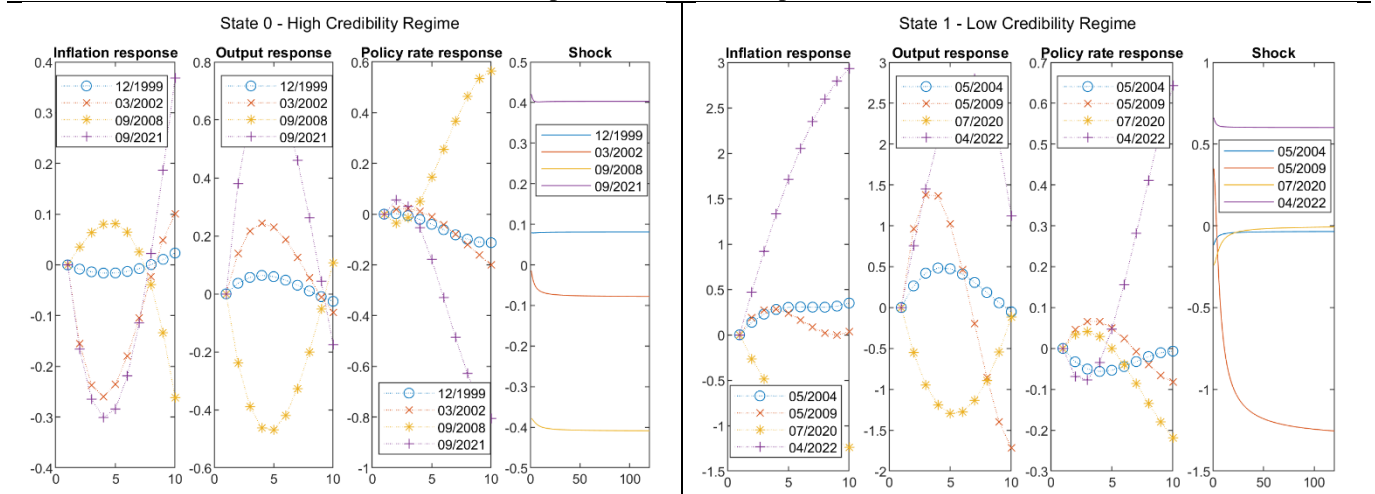Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Impulse response functions of output, inflation and the policy rate in the low and high credibility regimes.

Figure 17, 18 and 19 display inflation expectations (Panel A) and *ex-ante* real interest rates (Panel B) shock decompositions for the US, the UK and the euro area respectively in the low and high credibility regimes; these enable us to assess the contribution of level, slope and curvature factors to the shocks and the responses of macroeconomic variables. In the case of the US (Figure 17), in state 0 (the high credibility regime) the response of inflation (Panel A) is explained by all three factors, while in state 1 (the low credibility regime) changes in the level ($\Delta\beta_{1t}$) seem to be less important and the inflation response is primarily driven by changes in the slope and curvature. For output, the response is mainly explained by the curvature ($\Delta\beta_{3t}$) in state 0 and by the slope ($\Delta\beta_{2t}$) in state 1. Similar remarks can be made for the policy rate response. As for the *ex-ante* real interest rate shocks (Panel B), the inflation response is driven

primarily by $\Delta\beta_{1t}$ in state 0 while in state 1 $\Delta\beta_{2t}$ and $\Delta\beta_{3t}$ play a more important role. Output seems to be mainly explained by $\Delta\beta_{1t}$ in both states, while all three factors are equally important for the policy rate response in either state.

Figure 15. Euro area IRFs in the Time-varying FLP framework

Panel A. Responses to inflation expectations shocks

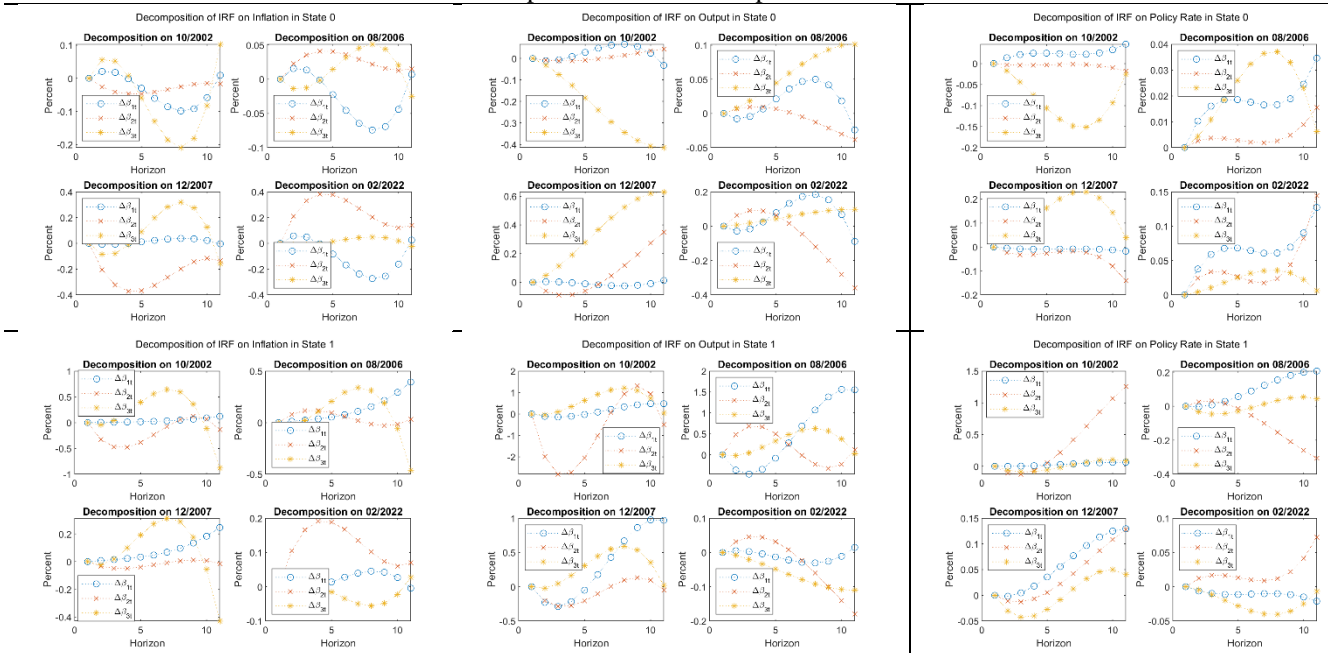Panel B. Responses to *ex-ante* real interest rate shocks
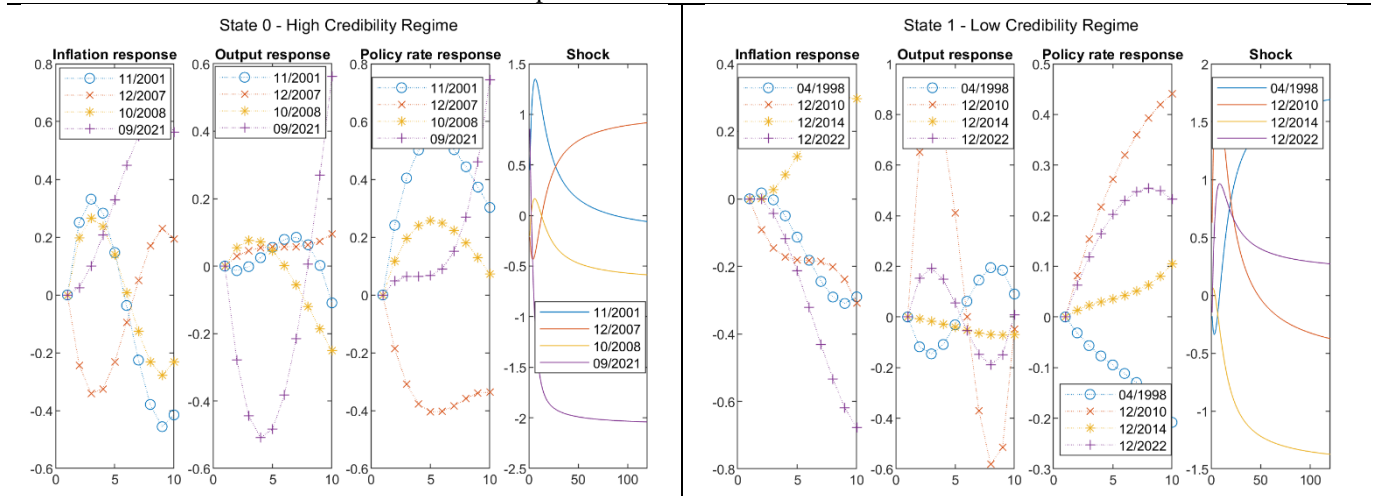
Notes: Impulse response functions of output, inflation and the policy rate in the low and high credibility regimes.

In the UK (Figure 18) the curvature factor $\Delta\beta_{3t}$ is the most important for explaining the inflation response to an inflation expectations shock in either credibility regime. Instead, output responds most strongly to changes in the slope $\Delta\beta_{2t}$, while the policy rate is explained by all three factors in both regimes. The inflation response to *ex-ante* real interest rate shocks is accounted for primarily by the slope in both regimes, and so is the output response in state 0. By contrast, in state 1 it is better explained by $\Delta\beta_{3t}$. The policy rate response is driven by the slope and curvature factors in both regimes, whereas the level factor seems to be largely

unimportant. On the whole, the differences between the low and the high credibility regime are less pronounced in the UK. Finally, in the euro area (Figure 19) the slope factor seems to be the least important for explaining the inflation, output and policy rate responses to inflation expectations shocks in state 0, while in state 1 the importance of each factor depends on the date of the shock. The responses of inflation, output and the policy rate to *ex-ante* real interest rate shocks are explained by all three factors in both regimes.

Figure 17. US Decomposition of FLP IRFs

Panel A. Responses to inflation expectations shocks

Panel B. Responses to *ex-ante* real interest rate shocks
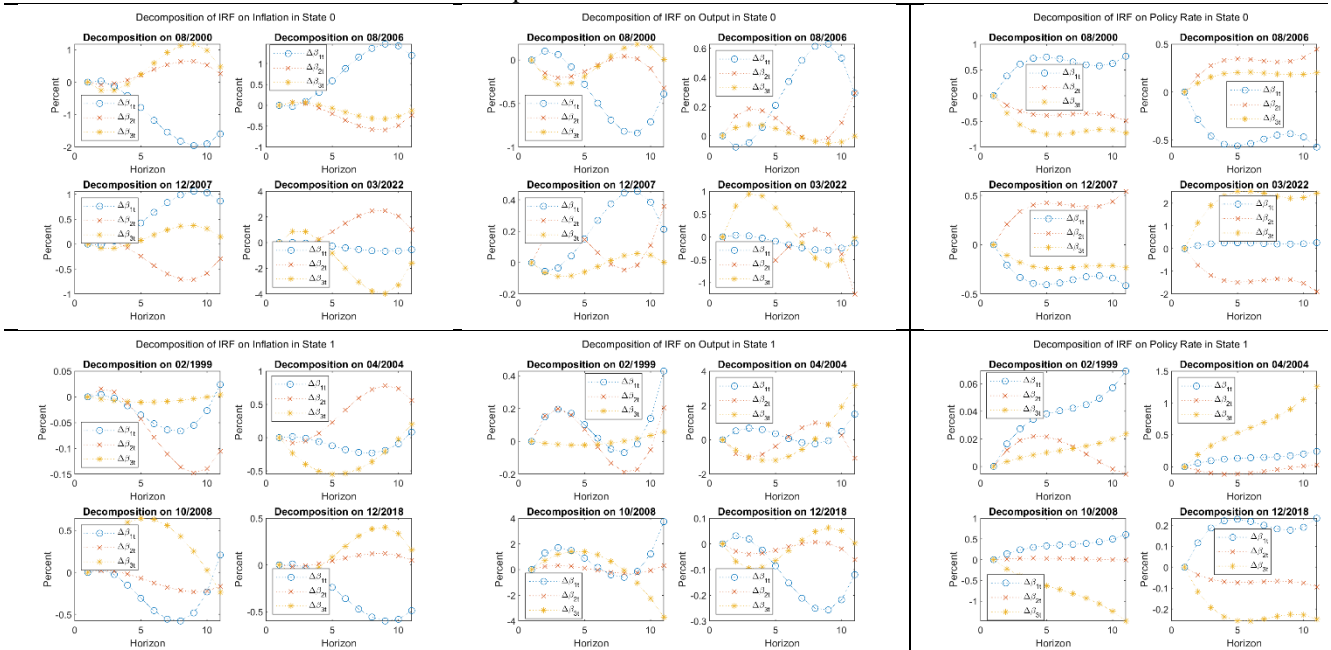
Notes: Plots of the decomposition of the responses related to shocks associated with level, curvature and slope of the term structure.

Figure 18. UK Decomposition of FLP IRFs
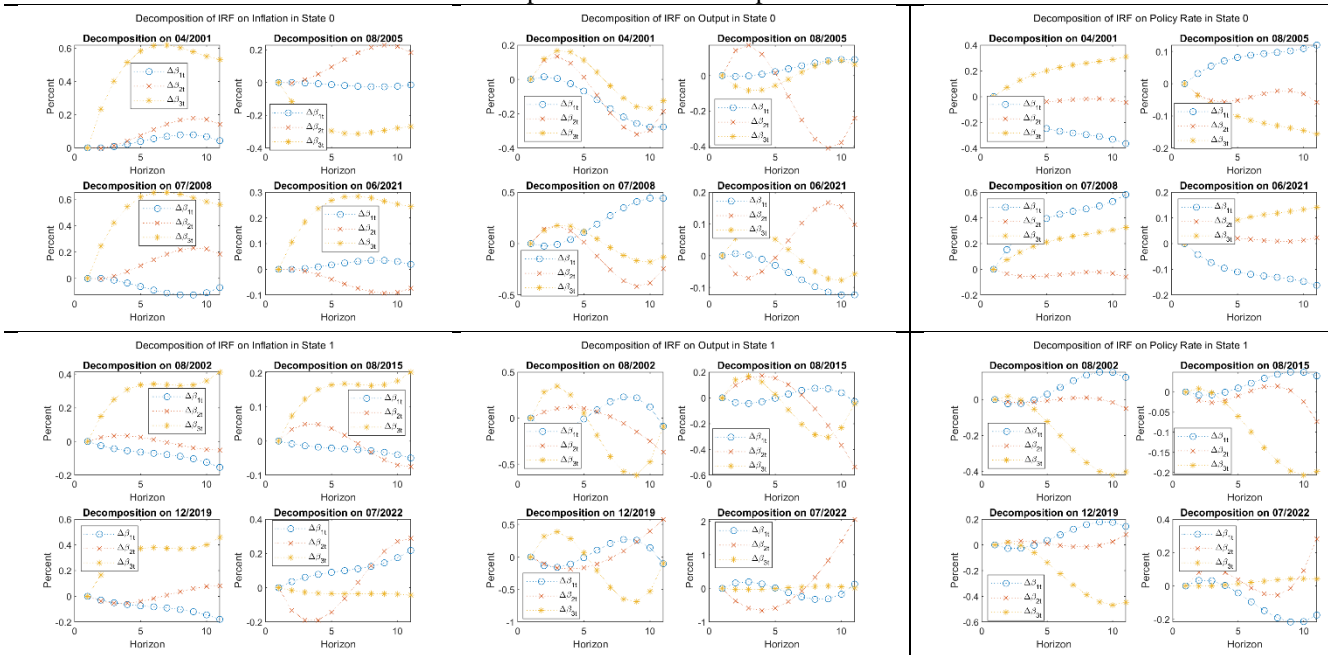
Panel A. Responses to inflation expectations shocks

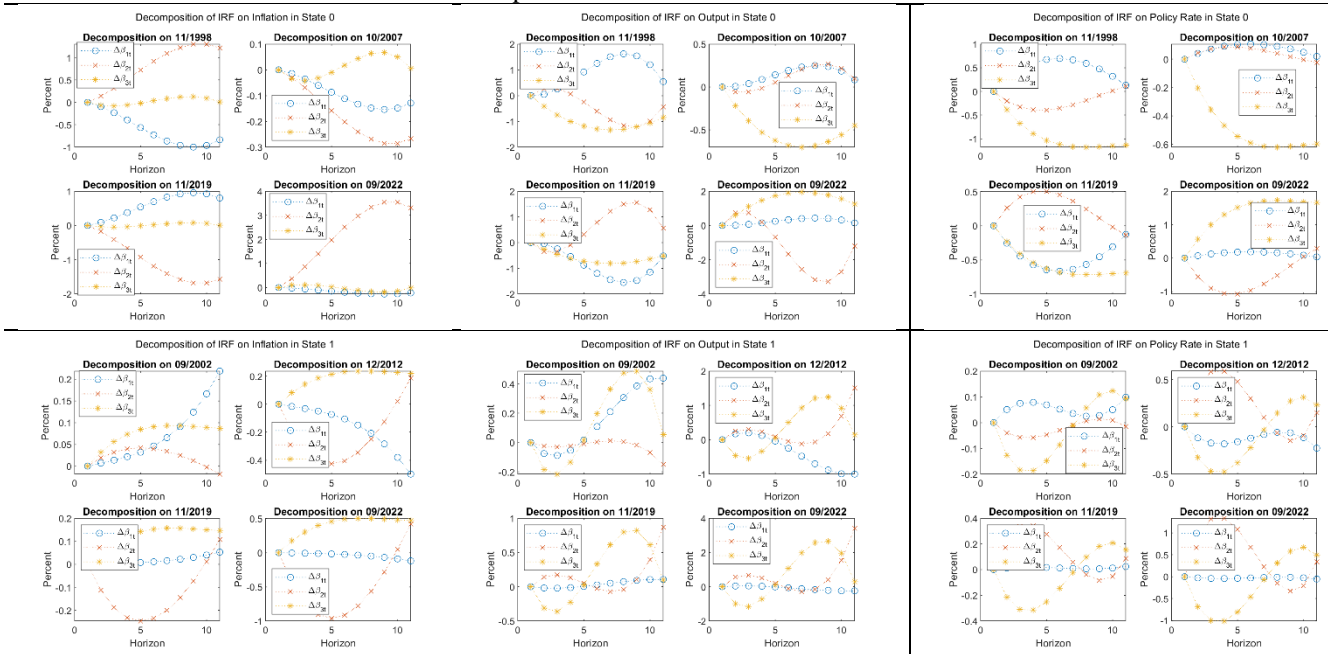Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Plots of the decomposition of the responses related to shocks associated with level, curvature and slope of the term structure.

Figure 19. Euro area Decomposition of FLP IRFs
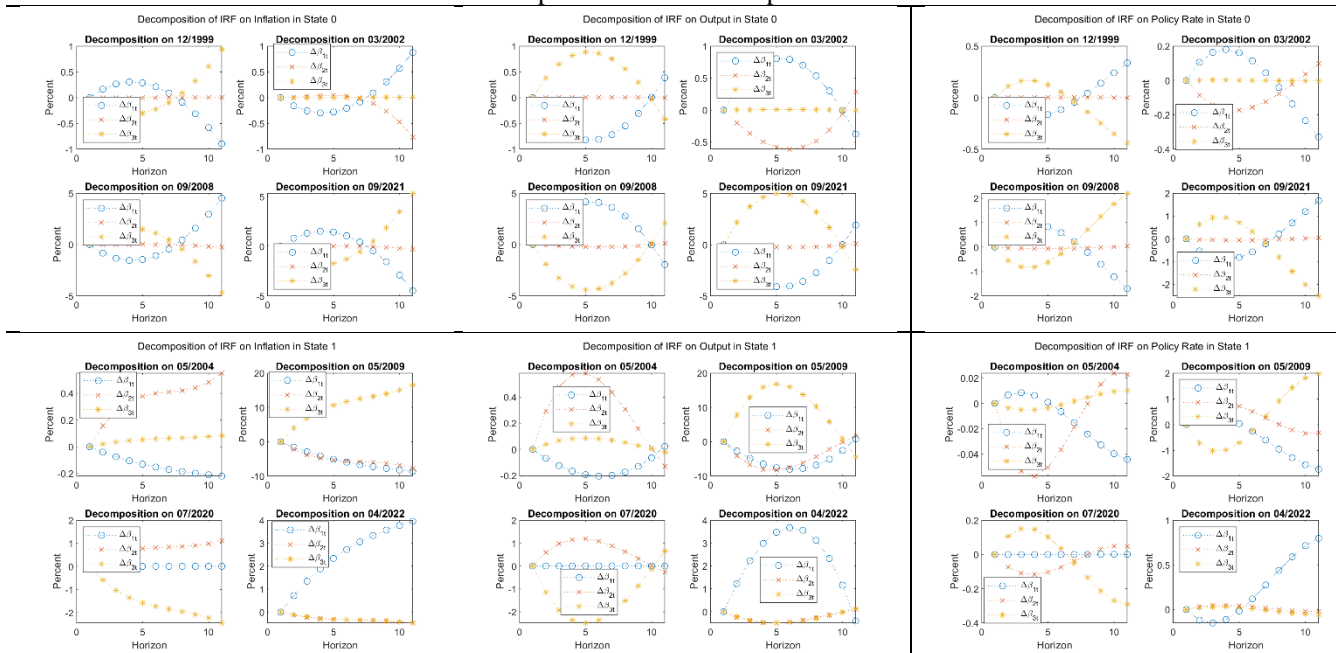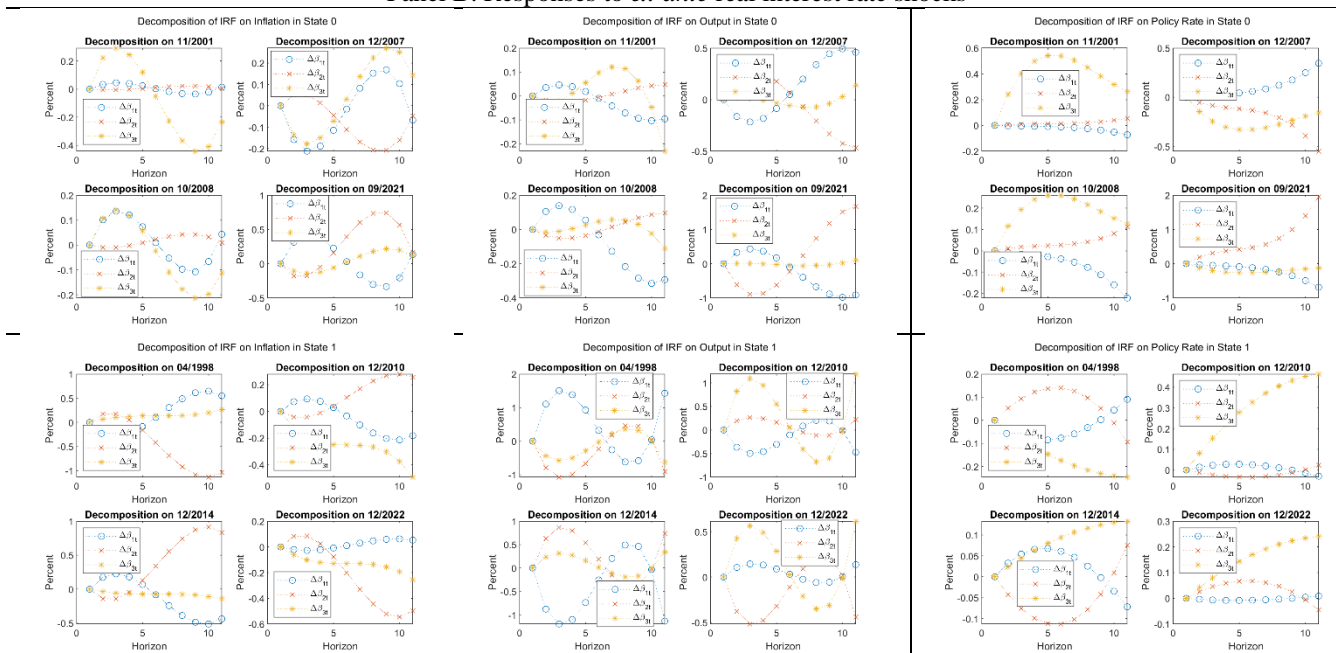
Panel A. Responses to inflation expectations shocks

Panel B. Responses to *ex-ante* real interest rate shocks

Notes: Plots of the decomposition of the responses related to shocks associated with level, curvature and slope of the term structure.

To sum up, it seems that in most cases, the slope and curvature factors play a more significant role than the level factor in driving the macroeconomic responses to inflation expectations and *ex-ante* real interest rate shocks. The slope factor is the difference between short- and long-term expectations, which contains important information about the shape of the term structure

and the anticipated path of de-anchoring, whilst the level factor captures long-term expectations only. The curvature factor represents the medium-term expectations which change the slope from positive to negative or vice versa at medium maturities. Therefore it appears that macroeconomic indicators respond mostly to the term structure elements of inflation expectations and *ex-ante* real interest rate shocks which would not have been captured using scalar shocks to short-term or long-term expectations only. This shows the importance of using functional shocks to assess accurately the macroeconomic impact of inflation expectations and *ex-ante* real interest rate shocks.

5. Conclusions

This paper investigates the macroeconomic effects of inflation expectations and *ex-ante* real interest rate shocks in the US, the UK and the Euro area from January 1998 to May 2023. These are estimated as functional shocks, namely as shifts in the entire functions corresponding to the term structures of inflation expectations and *ex-ante* real interest rates as in Inoue and Rossi (2021). Impulse responses and nonlinear functional local projections are then obtained from a linear functional VARX model in order to assess the macroeconomic impact of the functional shocks.

The main findings can be summarised as follows. First, in most instances, there are significant differences between inflation expectations and *ex-ante* real interest rate shocks at the short and long end of the term structure, which can only be captured by estimating functional shocks rather than scalar ones. Second, the VARX analysis reveals that inflation (output) responds strongly to inflation expectations (*ex-ante* real interest rate) shocks. Further, *ex-ante* real interest rate shocks are particularly important for monetary policy transmission at the long end of the term structure. Third, the nonlinear analysis shows that inflation expectations shocks which are mainly driven by long-term changes have similar economic effects as supply shocks, while those which are driven by short term changes have a similar impact to demand shocks. Moreover, *ex-ante* real interest rate shocks are found to be inflationary and expansionary in the presence of an inverted term structure, but deflationary and recessionary when this steepens. Fourth, the results of the decomposition of the macroeconomic responses to shocks indicate that the slope and curvature factors, which represent the medium-term and the distance between the short- and the long-term, are more important for explaining macroeconomic responses than

the slope factor which represents long-term expectations. Again, functional shocks provide important information which would be missed by traditional scalar shocks. Finally, the estimated macroeconomic effects of shocks are more consistent with theory when central bank credibility is low.

Our analysis provides useful information to monetary authorities. In particular, estimating the term structure of inflation expectations and of *ex-ante* real interest rates and monitoring their changes over time gives central banks useful insights into their short-, medium- and long-term behaviour and the inflation outlook. In addition, the findings on the transmission of inflation expectations and *ex-ante* real interest rate shocks to the economy can be used to design appropriate policies to anchor inflation expectations across all maturities of the term structure.

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Appendix A

The state-space representation used to estimate the term structure parameters follows the work of Aruoba (2020) and adapts the dynamic model developed by Diebold et al. (2006). The aim is to obtain an accurate estimate of the term structure with maturities ranging from 3 to 120 months from quarterly and monthly surveys. Owing to the features of the survey data some clarification on the notation and the usage of continuous compounding to represent different expectation maturities is provided in this Appendix. This is necessary since the way in which inflation expectations surveys are conducted does not consistently map to τ-month ahead forecasting horizons. Aruoba (2020) shows how to map each individual survey question to the correct τ-month ahead forecast horizon. We follow this procedure as explained below.

When converting the forecasts from different sources with monthly and quarterly release frequencies into a consistent monthly representation we denote by $\pi_t^e(\tau)$ a general inflation forecast made at time t for τ months in the future is represented as $\pi_{t \to t+\tau}^e$. For instance, a three-month forecast made between month t and month $t+3$ is denoted by $\pi_{t \to t+3}^e$, whereas the three-month forecast made between month $t+3$ and month $t+6$ is denoted by $\pi_{t+3 \to t+6}^e$. Using this notation, the inflation expectations measures can be written into the factor model as follows:

$$\pi_{t+\tau_1 \to t+\tau_2}^e = L_t + \frac{e^{-\lambda\tau_1} - e^{-\lambda\tau_2}}{\lambda(\tau_2 - \tau_1)}(C_t - S_t) + \frac{\tau_1 e^{-\lambda\tau_1} - \tau_2 e^{-\lambda\tau_2}}{\tau_2 - \tau_1}C_t \qquad (A1)$$

where $\pi_{t+\tau_1 \to t+\tau_2}^e$ is the period $t+\tau_2$ forecast of inflation made in period $t+\tau_1$, where the forecast horizon is $\tau_2 - \tau_1$. The properties of the notations used are quite attractive, since it relies on continuous compounding, which means that the inflation expectation between two periods is equal to the average monthly expectation between them. It then follows from $(A1)$ that the estimation of $\pi_{t+\tau_1 \to t+\tau_2}^e$ for any (τ_1, τ_2) only requires knowledge of the values of L_t, S_t, C_t and λ. Each question in any inflation expectations survey can be converted into a set of factor loadings using the general convention introduced above to yield measurement equations of the following general form:

$$x_t^i = \begin{pmatrix} f_L^i & f_S^i & f_C^i \end{pmatrix} \begin{pmatrix} L_t \\ S_t \\ C_t \end{pmatrix} + \varepsilon_t^i \qquad (A2)$$

where x_t^i is the generic observable, (f_L^i, f_S^i, f_C^i) are the factor loadings and ε_t^i is the measurement error. The mapping of different survey questions with different forecast horizons into measurement equations is outlined in detail in Aruoba (2020). Following this approach, we combine multiple measurement equations, each representing a different survey question in any one survey, into a state space system, which means that some observations are sparse owing to the quarterly frequency of some surveys, while for others multiple variables are used to inform a forecast value. The Kalman filter is able to deal with this structure via prediction-error decomposition.

Appendix B

Table B1. Inflation expectations survey data					
UK	**Frequency**	**Range**	**Forecast horizons**	**Source**	**Link**
Database of Average Forecasts for the UK Economy	Monthly	2004m1 – 2023m5	1-22	HM Treasury	https://www.gov.uk/government/statistics/database-of-forecasts-for-the-uk-economy
Inflation Attitudes Survey	Quarterly	1999m11 – 2023m5	12,24,60	Bank of England	https://www.bankofengland.co.uk/inflation-attitudes-survey/2023/may-2023
Market Participants Survey	Monthly with gaps	2022m2 – 2023m5	1,3,6,9,12,24,36,60	Bank of England	https://www.bankofengland.co.uk/markets/market-intelligence/survey-results/market-participants-survey-results-may-2023
Inflation forecast	Quarterly	1991m1-2023m5	12	OECD	https://data.oecd.org/price/inflation-forecast.htm
Euro area	**Frequency**	**Range**	**Forecast horizons**	**Source**	**Source Link**
HICP Inflation Forecasts	Quarterly	1999m1-2023m5	12,24,36,60	European Central Bank	https://www.ecb.europa.eu/stats/ecb_surveys/survey_of_professional_forecasters/html/table_hist_hicp.en.html
Survey of Professional Forecasters	Quarterly	1998m12 – 2023m5	3,12,24,60	European Central Bank	https://www.ecb.europa.eu/stats/ecb_surveys/survey_of_professional_forecasters/html/index.en.html
Consumer Expectations Survey	Monthly	2020m4 – 2023m5	12,36	European Central Bank	https://www.ecb.europa.eu/stats/ecb_surveys/consumer_exp_survey/results/html/ecb.ces_results_july_2023_inflation.en.html
Business and Consumer Survey	Monthly and quarterly	2004m1 – 2023m5	12	European Commission	https://economy-finance.ec.europa.eu/economic-forecast-and-surveys/business-and-consumer-surveys_en
Inflation forecast	Quarterly	1996m1-2023m5	12	OECD	https://data.oecd.org/price/inflation-forecast.htm
Notes: Forecast horizons in months					