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Abstract

This paper investigates the inflation effects of oil price expectations shocks constructed as functional shocks, i.e. as shifts in the entire oil futures term structure (both standard and risk-adjusted). The latter are then included in a vector autoregressive model with exogenous variables (VARX) to examine the US case. Counterfactual analysis is also carried out to investigate second-round effects on inflation through the inflation expectations channel. These are found to be significant, in contrast to earlier studies based on standard oil price shocks. Additional nonlinear local projections including a shock decomposition exercise show that inflation and inflation expectations are primarily driven by changes in the curvature (level and slope) factor when the latter are anchored (unanchored). These findings provide useful information to policymakers concerning the impact of oil price expectations on inflation and inflation expectations.

JEL-Codes: C320, E310, Q430.

Keywords: functional shocks, oil price expectations, inflation anchoring, counterfactual analysis.

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1. Introduction

Few global variables have received as much attention in the literature as oil prices. In particular, the macroeconomic impact of oil price shocks is of key interest to both economists and policymakers. It is now well established that such shocks can be important determinants of inflation (Kilian, 2008c; Choi et al., 2018) and inflation expectations (Coibion and Gorodnichenko, 2015; Nasir et al., 2020a, 2020b; Kilian and Zhou, 2022a, 2022c). The recent literature has focused in particular on their possible second-round effects on inflation through the inflation expectations channel. Because of the existence of this propagation mechanism the management of inflation expectations in the presence of oil price shocks represents a key task for central banks. Existing studies provide limited empirical support for second-round effects in the case of real oil price shocks (Wong, 2015), whilst there is stronger evidence for real gas price shocks (Boeck and Zörner, 2023). However, the role of oil price expectations shocks is yet to be investigated. The present study aims to fill this gap in the literature by providing new evidence on how such shocks can affect inflation directly and indirectly through the inflation expectations channel. As in Inoue and Rossi (2021), the analysis is based on functional shocks defined as shifts in an entire function; in the case of the oil market, this is represented by the term structure of oil futures, which allows one to observe shifts in oil price expectations at short, medium and long horizons simultaneously. Oil futures reflect more accurately agents' expectations about oil prices than the spot price of crude oil which can differ substantially from the intermediate oil prices faced by firms (Kilian, 2008b). Although the oil futures term structure has previously been used to obtain measures of oil price expectations (see Baumeister and Kilian, 2014; 2016), the existing literature has not used functional oil price expectations shocks defined as shifts in oil futures prices across all maturities or assessed their effects on inflation and inflation expectations.

We analyse these issues by constructing functional oil price shocks as shifts in the term structure of West Texas Intermediate (WTI) oil futures. To account for the possible existence of a time-varying risk premium, we also create a risk-adjusted oil futures term structure using the method of Hamilton and Wu (2014). The term structure parameters to compute the functional shocks are estimated using the Nelson-Siegel model. We then use the functional oil price expectations shocks for both standard and risk-adjusted term structures separately in a vector autoregressive model with exogenous variables (VARX) to investigate their effects on inflation and inflation expectations in the US. Counterfactual analysis is then carried out to assess the possible second-round effects of oil price shocks on inflation through the inflation expectations channel. Next, nonlinear functional local projections are used to investigate to what extent these effects vary with the degree of inflation expectations anchoring. This method also allows us to ascertain which term structure factor makes the strongest contribution to the response of economic aggregates to functional oil price expectations shocks. Finally, as an extension we consider different measures of inflation expectations as well as functional shocks derived from Brent crude oil futures prices.

On the whole, the present study makes a fourfold contribution. First, to our knowledge it is the first to investigate the transmission of shocks to oil price expectations to inflation and inflation expectations. Second, it derives oil price expectations from both standard and risk-adjusted oil futures, which allows to differentiate between the oil price expectations of policymakers and those of financial market participants. Third, oil price expectations shocks are defined as shifts in an entire function instead of a scalar, thereby capturing changes at short, medium and long horizons. Fourth, counterfactuals are generated which, unlike standard impulse response functions or historical decompositions, provide information about the role of inflation expectations in transmitting the functional oil price expectations shocks to inflation. Thus the relative importance of direct and second-round effects of oil price expectations shocks is assessed for the first time in this study.

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature, Section 3 outlines the empirical framework, Section 4 discusses the results, Section 5 presents some extensions and Section 6 offers some concluding remarks.

2. Literature Review

There are three strands of the literature which provide a background to the present study, which focus respectively on oil-related shocks, inflation and inflation expectations; counterfactuals and second-round effects; measures of oil price expectations.

A considerable number of studies have been devoted to investigating the effects of oil price shocks on inflation and have often found that they are significant (Kilian, 2008c; Bachmeier and Cha, 2011; Gao et al., 2014). Kilian (2008a; 2008b) suggests to distinguish between oil supply and demand shocks and reports that the former have no effects on inflation, while the latter causes a small lagged response. Choi et al. (2018) study the impact of global oil price fluctuations on inflation in a panel of advanced and developing countries. They report that oil price shocks increase inflation, but their overall impact seems to have declined over time with the increase in central bank credibility. Coibion and Gorodnichenko (2015) find that increasing household inflation expectations in the US can almost entirely be attributed to higher oil prices. Kilian and Zhou (2022a) highlight that the response of inflation expectations to gas price shocks varies over time and argue that vector autoregressive models with appropriate restrictions should be preferred to static regression models. In contrast to Coibion and Gorodnichenko (2015), they report that less than half of the variation in US short-term household inflation expectations is accounted for by gasoline price shocks. Kilian and Zhou (2022c) detect sizeable effects of gasoline price shocks on US inflation expectations, but these are not very persistent and only affect short-term expectations. Other studies find that the effects of oil price shocks on inflation expectations are asymmetric, being influenced by past expectations and by the degree to which they were anchored in the UK and New Zealand (Nasir et al., 2020a) as well as in the Scandinavian countries (Nasir et al., 2020b).

Considering inflation expectations allows to distinguish between direct and second-round effects of oil price shocks on inflation. The former occur through the cost channel, with higher energy costs driving up input costs and thus inflation, while the latter increase inflation through the inflation expectations resulting from the wage bargaining and price setting processes. Recently, there has been increasing interest in investigating the propagation of oil price shocks to inflation. Wong (2015), for instance, assesses the second-round effects of oil price shocks to US inflation through the inflation expectations channel. The results of his counterfactual analysis suggest that inflation expectations only play a minimal role in transmitting oil price shocks to inflation. Boeck and Zörner (2023) conduct counterfactual analysis using a structural VAR model with sign restrictions to investigate how inflation expectations propagate the inflationary effects of natural gas price shocks in the euro area. Their evidence points to stronger effects of short- rather than long-term expectations. An extension to the analysis shows much weaker second-round effects of crude oil price shocks. Knowledge of the such effects is crucial for monetary authorities since, although they cannot directly influence global oil prices, they can put measures in place to influence the propagation to domestic prices. Such second-round effects are found to be particularly strong in the case of central banks with low credibility (Binder, 2018).

A separate, relatively small literature focuses on future oil price expectations, one possible measure of which is based on survey responses. For instance, Prat and Uctum (2011) use Consensus forecast survey data on WTI oil price expectations for the 3- and 12-months horizons and reject the hypothesis that they are rational, since they appear to be characterised by significant forecast errors. However, outside of professional forecasts, no data exist on household or firm expectations of future oil prices. An important source of information about the expectations of agents regarding future oil price developments are oil futures markets (Baumeister, 2023). Baumeister and Kilian (2016), for instance, compare different measures of oil price expectations, including those of economists, policymakers, consumers and financial market participants, and report that the most accurate one can obtained by using the method of Hamilton and Wu (2014). Baumeister (2023) tests the forecasting properties of oil futures prices and finds that they do not represent a rational expectation of the future spot price of oil, since the futures-spot price differential only accounts for a very small portion of subsequent oil price changes.

3. Empirical Framework

3.1 The oil futures term structure

International organisations such as the International Monetary Fund and central banks around the world often derive oil price expectations from oil futures prices. Since future contracts allow market participants to lock in today a price at which they can purchase crude oil at a fixed date in the future, the price of the futures contract with maturity h represents the h-period ahead market expectation of the price of crude oil. Despite its simplicity and popularity, this measure of oil price expectations can only be fully accurate if one takes into account the existence of a risk premium. For this purpose, we follow the approach of Hamilton and Wu (2014), who estimate the time-varying risk premium directly from current and past oil futures prices. Compared to other methods of calculating risk-adjusted oil futures prices, the Hamilton-Wu one appears to produce the most accurate measure of oil price expectations at both the quarterly and monthly frequency (Baumeister and Kilian, 2014). It is based on an affine factor structure which allows to identify risk premia as the differences between futures prices and the rational expectation of future prices. One can then obtain risk-adjusted oil futures prices by subtracting the Hamilton-Wu risk premium estimates from the oil futures price at any given horizon, which can be seen as representative of financial market expectations of the future price of oil (Baumeister and Kilian, 2016). This method is sensitive to the choice of breakpoints. For instance, in their full sample estimation Hamilton and Wu (2014) notice a change in the risk premium since the beginning of 2005 and thus split their sample accordingly. The sub-sample results for the risk premium differ substantially from the full sample ones. In our estimation, we allow for two breaks, one coinciding with the 2005 one identified by Hamilton and Wu (2014), and the other in June 2011, at the end of their sample. The model is estimated using weekly data and the estimates of the risk premium are subsequently averaged over the month to obtain the market expectations measure (Baumeister, 2023).

We follow the well-known Nelson-Siegel (1987) approach to estimate the term structure parameters from the standard and risk-adjusted oil futures term structures:

$$f_t(\tau) = L_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau}\right) S_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right) C_t\,, \qquad \lambda > 0 \tag{1}$$

where $f_t(\tau)$ is the oil futures price for a given time to maturity τ, L_t, S_t and C_t are the level, slope and curvature factors, respectively, and λ is a factor which determines the contribution of S_t and C_t to the term structure curve relative to L_t. The functional oil price shocks are then defined as shifts in the entire oil futures term structure, i.e. a simultaneous shift in L_t, S_t and C_t which can be represented by a vector X_t containing the functional shocks and defined as follows: $X_t = \{\Delta L_t, \Delta S_t, \Delta C_t\}$.

3.2 A VARX model with counterfactual analysis

After obtaining the functional oil price expectations shocks from the oil futures term structures, we proceed to investigate their impact on inflation and inflation expectations. Specifically, we estimate the following structural vector autoregressive model with exogenous variables (VARX):

$$Y_t = \mu + A(L)Y_t + \Theta X_t + u_t \tag{2}$$

where Y_t is a (4×1) vector of endogenous variables including inflation (π_t), inflation expectations (π_t^e), output (y_t) and the policy interest rate (i_t). X_t contains the functional shocks which are exogenous to the model. In order to account for long and variable lags in the transmission of functional oil price shocks we allow for up to 12 lags in the model, which is standard procedure in the VAR literature concerned with such shocks (Kilian and Lewis, 2011).

For identification purposes we use a combination of zero and sign restrictions, which are detailed in Table 1 (Kilian and Zhou, 2022a, Kilian and Zhou, 2022b). As we will show, this identification approach is suitable for the following counterfactual analysis aimed at distinguishing between the direct and second-round effects of oil price shocks on inflation through the inflation expectations channel. In addition to oil price shocks, we identify standard shocks including supply, demand and monetary shocks as well as an idiosyncratic inflation expectations shock, all of which can be sources of inflationary pressures. A negative supply (cost-push) shock is assumed to increase inflation and inflation expectations, but decrease industrial production on impact. A positive demand shock increases inflation, inflation expectations and industrial production on impact. We also assume that the central bank follows a forward-looking Taylor rule and therefore increases the interest rate immediately in response to a positive demand shock. However, since output and inflation react with opposite signs to a supply shock, it is not obvious how the central bank will respond in such a case. A contractionary monetary shock increases the interest rate on impact but lowers inflation, which is relatively standard in the literature using VARs with sign restrictions (Boeck and Zörner, 2023). We do not restrict the response of inflation expectations since we do not want to assume any particular inflation expectations formation process. We also identify an idiosyncratic inflation expectations shock, which raises only inflation expectations on impact. The inclusion of this shock allows us to offset the transmission channel of functional oil price expectations shocks through inflation expectations in the subsequent counterfactual exercise without changing the estimated structural relationships of the VARX model. Demand and supply shocks which could increase inflation expectations are already captured by the restrictions imposed previously.

The restrictions placed on the responses to functional oil price shocks deserve some clarification. As pointed out by Kilian (2008c), a positive oil price shock is expected always to be recessionary, hence the negative sign on the output response. However, depending on whether the demand or the cost channel dominates, its effect may either be deflationary or inflationary. For this reason, we do not restrict the response of inflation, which also allows us to determine whether the functional oil shocks are more representative of demand or supply shocks, since the literature has established that the effect of oil shocks can differ depending on whether the underlying shock stems from changes in oil demand or supply (Kilian, 2008c).

Table 1. Sign restrictions in the VARX					
	Supply (cost-push)	**Demand**	**Monetary policy**	**Expectations**	**Functional oil**
π_t	$(+)$	$(+)$	$(-)$	0	
π_t^e	$(+)$	$(+)$		$(+)$	
y_t	$(-)$	$(+)$		0	$(-)$
i_t		$(+)$	$(+)$	0	

Notes: Sign restrictions with $(+)$ indicating a positive response to the shock and $(-)$ indicating a negative response.

We can use the estimated relationships from the VARX model to generate counterfactuals to assess the significance of the inflation expectations channel in transmitting the functional oil price expectations shocks to inflation. Specifically, in order to construct a counterfactual we estimate the VARX twice, once as specified in equation (2), and once with the inflation expectations response to the functional oil price shocks shut down. The second-round effects are then captured by the difference in impulse response functions between the two models, which should be large if oil price expectations shocks are important as a propagation mechanism to inflation.

3.3 Nonlinear functional local projections

In the following analysis we investigate whether the effects of the functional oil price shocks depend on the extent to which inflation expectations are anchored. The literature has reached the conclusions that their anchoring and the degree of central bank credibility in general can influence the transmission of shocks stemming from the oil market (see, e.g., Wong, 2015; Binder, 2018; Choi et al., 2018). On the basis of the VARX model presented in the previous section, we then estimate nonlinear functional local projections (FLP) which take the following form:

$$Y_{t+h} = \mu_{h,t} + \Theta_{h,t}^{(1)} L_{t-1}^{d} + \Theta_{h,t}^{(2)} S_{t-1}^{d} + \Theta_{h,t}^{(3)} C_{t-1}^{d} + \varphi_t' Y_{t-1} + e_{h,t+h} \qquad (3)$$

where Y_t is a vector containing the same variables as in (2) before, $h = 1,2, \dots 10$ is the response horizon, $\Theta_{h,t}^{(j)}$ are the time $(t+h)$ responses to the structural shocks at time t for $j = 1,2,3$, and d_t is a threshold variable which indicates the regime of inflation expectations anchoring. We define anchored time periods as those in which both short-term (12-months) and long-term (10-year) inflation expectations are within a 100-basis point range either side of the inflation target of 2%. Any periods during which inflation expectations are outside this range are defined instead as unanchored times. The dummy variable takes a value of 1 during anchored times and of 0 during unanchored times. The nonlinear functional local projections allow us to decompose the IRFs to ascertain which term structure factor makes the strongest contribution to the macroeconomic responses.

3. Data and Empirical Results

4.1 Data Description

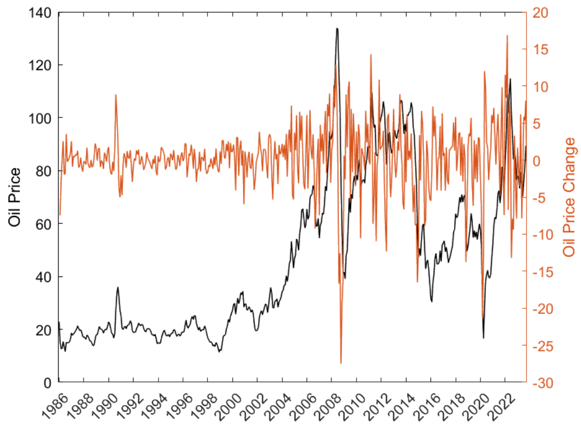
The New York Mercantile Exchange (NYMEX) provides contracts for WTI futures. We use the generic futures contracts CL1-CL9 (1- to 9-months maturity), CL12 (12-months maturity), CL18 (18-months maturity) and CL24 (24-months maturity) from January 1990 until October 2023, which is a common choice in the literature, since they represent the most commonly traded and liquid oil futures (Paschke and Prokopzcuk, 2009; Heidorn et al., 2015; Cummins et al., 2016; Kearney and Shang, 2020; Bredin et al., 2021). A detailed description of these data is provided in Appendix A. The WTI crude oil price series is obtained from the Federal Reserve Bank of St Louis (FRED) from January 1986 until October 2023.

We conduct the analysis for the US, which is the focus of most empirical studies on the transmission of oil price shocks. The inflation series is constructed using the headline consumer price inflation (CPI) obtained from the OECD Inflation (CPI) database. We have also retrieved core CPI from the same source for comparison purposes. The industrial production index which is used as a proxy for output is taken from FRED and converted to its annual growth rate. The central bank policy rate is obtained from the Bank for International Settlements (BIS) central bank policy rates dataset. Inflation expectations are the Michigan survey 1-year inflation expectations series. We use household surveys of inflation expectations since they inform the wage bargaining process and therefore generate potential second-round effects. Since Coibion and Gorodnichenko (2015) point out that in the US two-thirds of firms are small or medium-sized enterprises which are unlikely to engage in professional forecasts but do employ individuals from households, their forecasts are assumed to closely relate to those of households. The general consensus in the literature is that short-term inflation expectations are more relevant for inflation than long-term ones (Fuhrer et al., 2012; Boeck and Zörner, 2023), which is why initially we perform the analysis using the former.

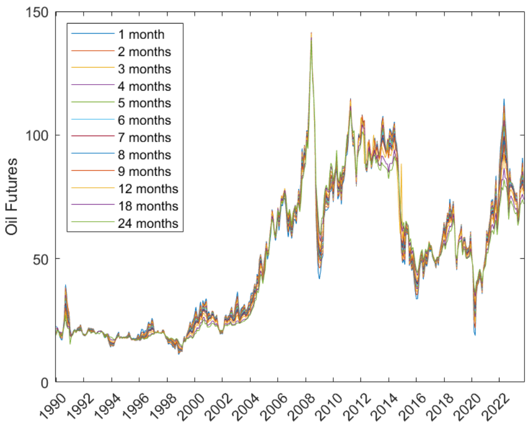
Then, as an extension, we consider different inflation expectations measures. Long-term survey inflation expectations are the 5- to 10-year inflation expectations series from the Michigan survey of consumers. Market-based inflation expectations are represented by the 10-year breakeven inflation rate, calculated as the difference between nominal and real government bond yields at 10 years maturity, which is obtained from Bloomberg. However, the series is only available since the early 2000s, which means that for the analysis including market inflation expectations we use a shorter sample. We also extend the analysis by using data for Brent crude oil futures prices; these are provided by the International Petroleum Exchange (IPE) and obtained from Bloomberg.

Figure 1. WTI oil price and futures

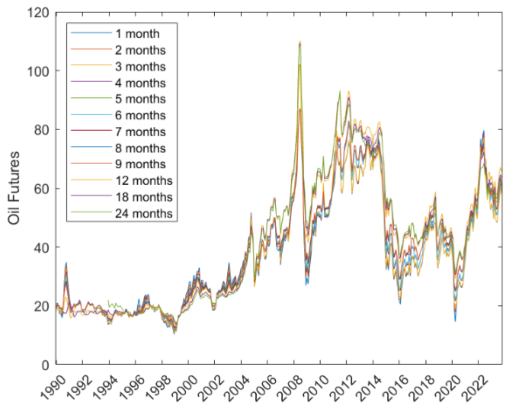
Panel A. WTI price and growth



Panel B. WTI oil futures



Panel C. Risk-adjusted WTI oil futures



Notes: Panel A shows the WTI price and its rate of growth over time. Panel B displays the oil futures with different maturities over time and Panel C displays the risk-adjusted oil futures with different maturities over time.

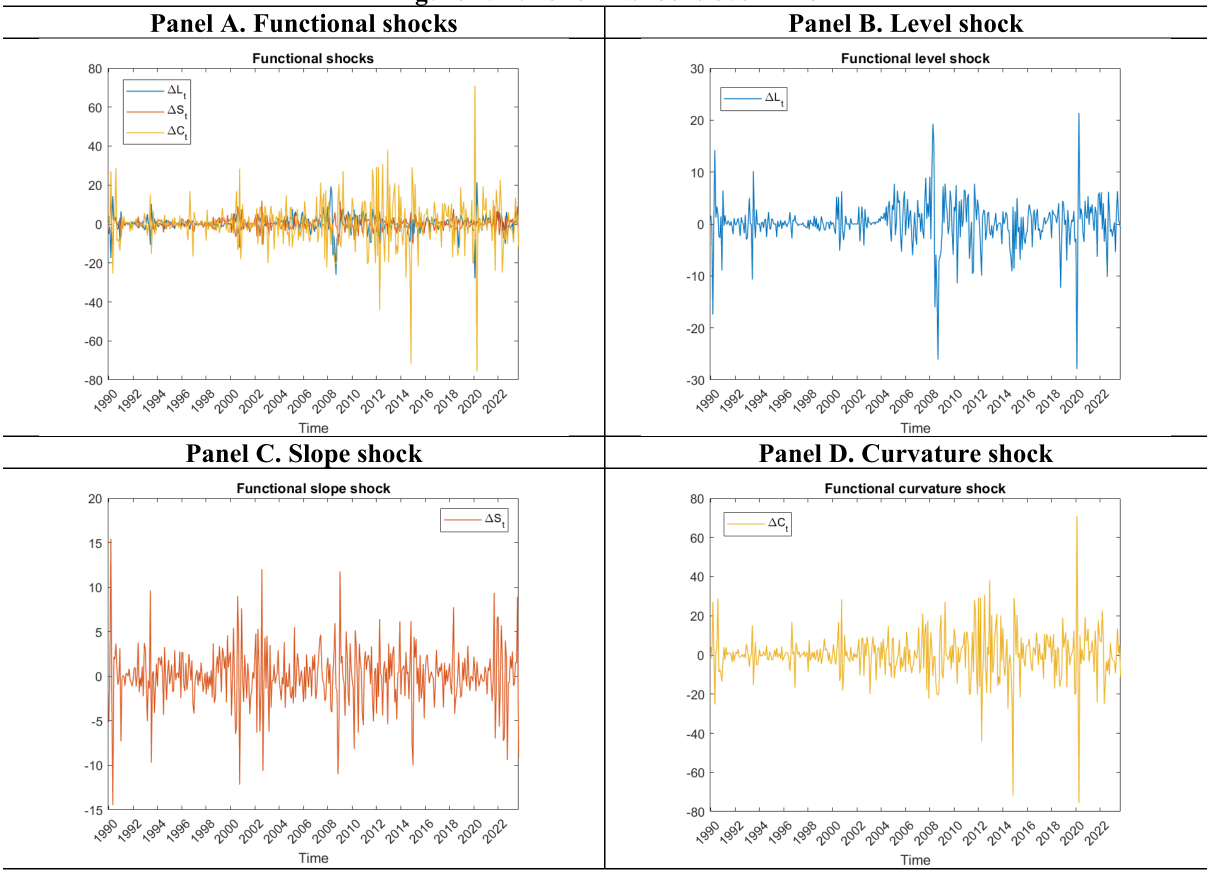
In Figure 1, Panel A displays the historic WTI crude oil price series, which fluctuates considerably over time. Oil price movements were often unexpected, and were subsequently attributed to either supply shocks stemming from oil production changes or the discovery of new oil fields and extraction methods, or demand shocks related to unexpected changes in the global business cycle, or expectations shocks represented by changes in the demand for above-ground oil inventories which indicate a shift in the expectations of future supply relative to future demand of crude oil (Baumeister and Kilian, 2016). Most historic oil price fluctuations can be explained by shifts in demand for crude oil, rather than changes in oil production. Some of these demand-side shocks can be related to shifts in the demand for oil inventories which are purchased to hedge against future crude oil shortages. Apart from the direct demand for oil inventories, demand for oil futures can be seen as representative of expectations of future oil prices. In Figure 1, Panels B and C show that the standard and risk-adjusted WTI futures prices followed the same pattern as the WTI price, although there is a greater dispersion of futures prices at different maturities in the risk-adjusted case, which indicates a widening gap between short- and long-term expectations of financial market participants regarding the future price of oil at different points in time.

4.2 Functional oil price shocks

The functional oil price expectations shocks for the standard and risk-adjusted case are displayed in Figures 2 and 3, respectively. There are sizeable shocks to all three term structure factors, which indicates that all three contribute to overall oil price expectations shocks. The term structure factors themselves can be interpreted as follows. The level factor describes the average change in prices across all maturities and represents the long-term component. The slope factor reflects the distance between changes in the short- and long-term price and can be interpreted as the short-term component. The curvature factor can be seen as an indicator of the speed at which expectations in the oil futures market change, since they represent medium-term maturities (Horváth et al., 2023). These characterisations imply that a shift in the level factor affects prices equally for all maturities, one in the slope factor affects prices more at shorter maturities, while one in the curvature factor affects mainly prices in the medium term and thus the shape of the term structure, i.e. the size of the hump.

Next, we examine the effects of several historic oil price shocks constructed as functional shocks. The invasion of Kuwait in August 1990 generated a strong increase in the price of oil (see Figure 1), which has been attributed to both supply and demand side factors. The functional oil price shock in Figure 4 indicates that oil futures prices increased across all maturities in August 1990, especially at the short end. By contrast, the risk-adjusted term structure shifted downwards more at the medium to long horizons. The shock in March 2003, which is related to the Iraq war, led to a small downward shift in the oil futures term structure at shorter maturities, but almost no movement at longer maturities. In the risk-adjusted case, instead, there was an upward shift across all maturities.

Figure 2. Functional shocks over time

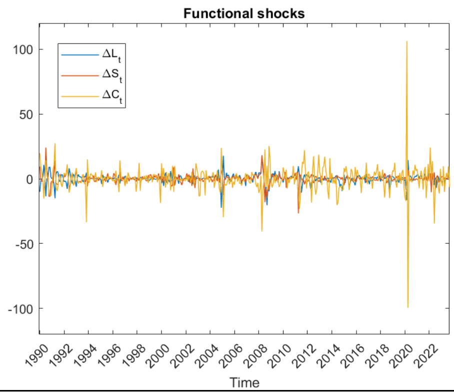


Notes: Panel A displays all functional shocks over time, while the other panels display the term structure factor shocks individually.

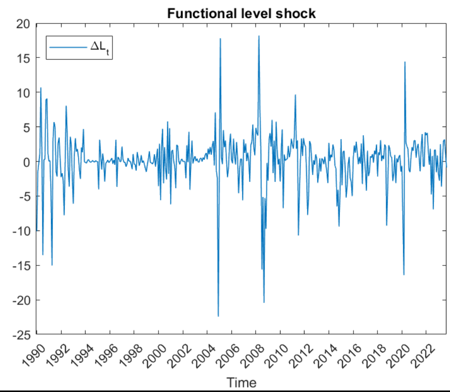
In January 2008, during the global financial crisis, the entire term structure increased sharply, but in the risk-adjusted case the shift at the short end was relatively small. In December 2008, for the first time the curve was not inverted. The shift was negative in both the standard and risk-adjusted case, which indicates expectations of falling oil prices. The 2011 Lybian uprising saw an increase in the oil futures term structure similar to that of January 2008. The decline in the price of oil in December 2014 was driven by an additional unexpected deterioration of the global economy following a previous weakening since June 2014. Oil futures prices decreased sharply at short maturities and increased at longer ones in the standard case, but decreased for all maturities in the risk-adjusted case. At the beginning of the Covid-19 pandemic in April 2020 there was a positive shift in both term structures at longer maturities, but a negative one at short maturities in the risk-adjusted case. After the Russian invasion of Ukraine, the oil futures term structures increased, with a noticeably smaller (larger) shift at short maturities in the standard (risk-adjusted) case.

Figure 3. Risk-adjusted functional shocks over time

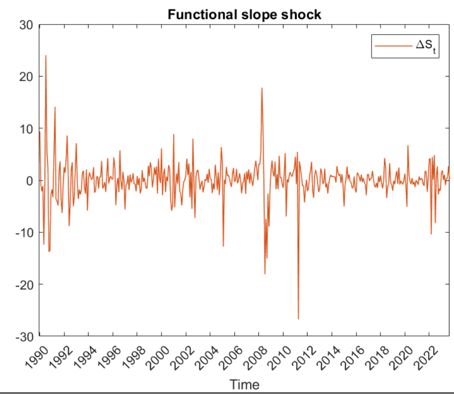
Panel A. Functional shocks



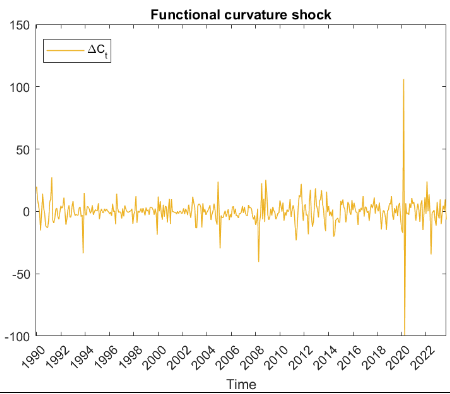
Panel B. Level shock



Panel C. Slope shock



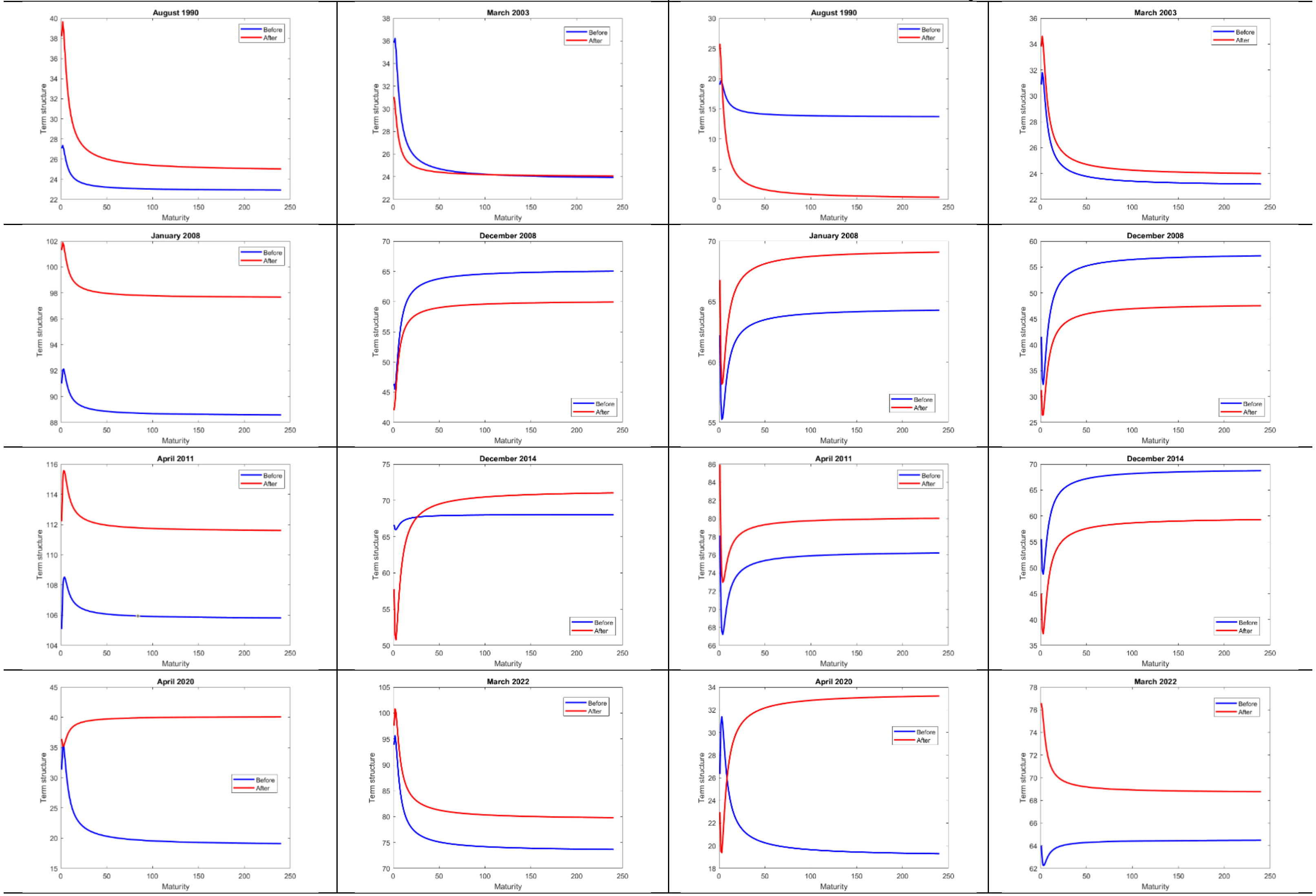
Panel D. Curvature shock



Notes: Panel A displays all functional shocks over time, while the other panels display the term structure factor shocks individually.

Figure 4. Shifts in the oil futures term structure during key historic events

Panel A. Standard term structure | **Panel B. Risk-adjusted term structure**



Notes: The solid blue line depicts the oil futures term structure before the shock and solid red line after the shock.

4.3 Direct and second-round effects

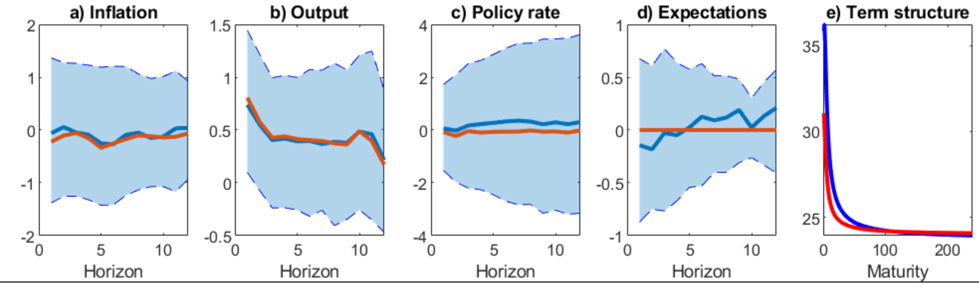
In this section, we examine the direct and second-round effects of the functional oil price expectations shocks using impulse response functions (IRFs) obtained from the VARX. We conduct the analysis using headline inflation and short-term survey expectations. In all cases, the median impulse response functions are displayed as solid blue lines with their 68 percent confidence bands as blue shaded areas, while the counterfactual with the expectations channel shut off is represented by the solid orange line. We report the results for the individual shocks according to whether they occurred during times when inflation expectations were anchored or unanchored.[1]

Figures 5 and 6 display the responses to functional oil price expectations shocks derived from the standard oil futures term structure at times when inflation expectations were anchored and unanchored respectively. The inflation response to functional oil price expectations shocks is close to zero for most events in both anchored and unanchored times. The response of industrial production is positive (negative) in anchored (unanchored) times. During anchored (unanchored) times inflation expectations react negatively (positively) initially but the response increases (decreases) over most of the remaining horizon. Inflation expectations seem to respond positively (negatively) to unambiguously positive (negative) functional oil price expectations shocks. When there are differences in the term structure shift between shorter and longer maturities, inflation expectations seem to respond in accordance with the shift at the short end. A second-round effect occurs if an oil price expectations shock causes a change in inflation expectations which subsequently influences inflation. In a well-anchored inflation environment, inflation should only be affected through the cost channel but not the inflation expectations one, and thus there should be no second-round effects through the latter (Boeck and Zörner, 2023). Indeed we find evidence of second-round effects, represented by the distance between the solid blue and the solid orange lines, which in most cases appear to be inflationary but on the whole are rather modest in the case of standard functional oil price expectations shocks. During anchored times the policy response in the presence of second-round effects seems to be contractionary and around one percentage point larger than in absence of any such effects. Instead, in unanchored times it is slightly expansionary and the difference between the standard and counterfactual IRFs is smaller.

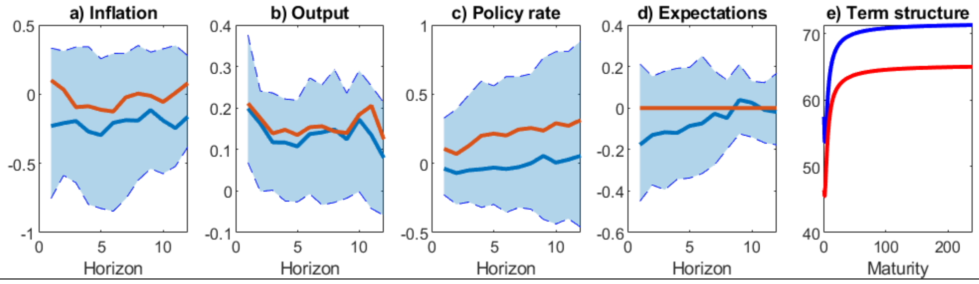
[1] As already mentioned in section 3.3, we define an anchored period as one during which both short-term and long-term survey inflation expectations are within a 100 basis point range either side of the inflation target of 2%.

Figure 5. Responses to standard shocks in anchored times

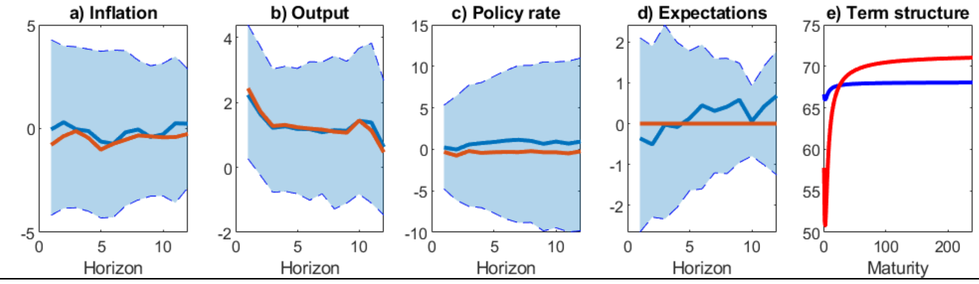
Panel A. March 2003



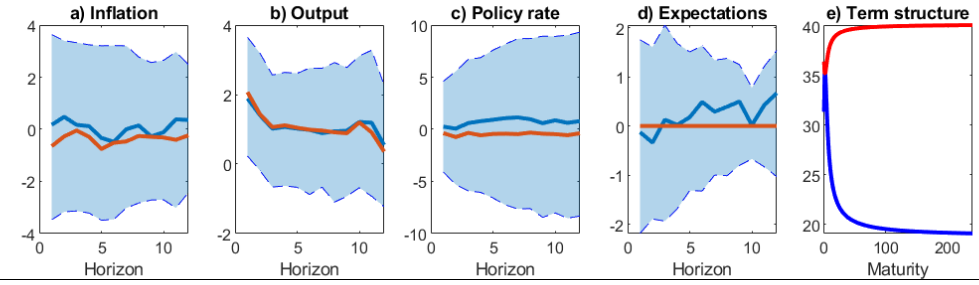
Panel B. December 2008



Panel C. December 2014



Panel D. April 2020

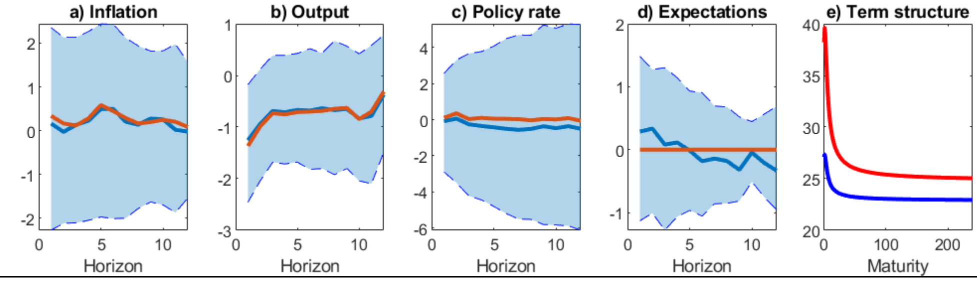


Notes: IRFs to functional oil price expectations shocks. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

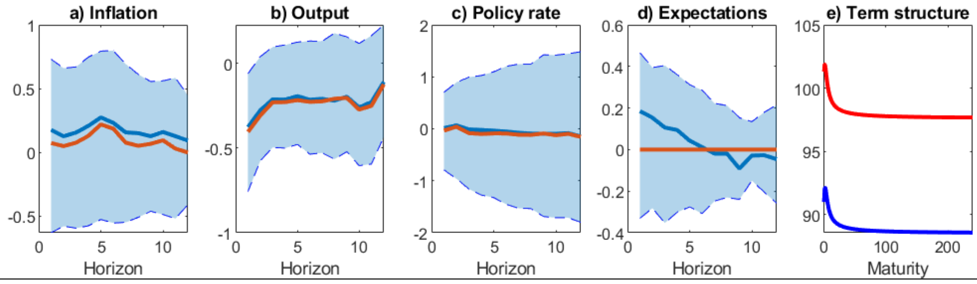
We are also interested in establishing whether the functional oil price shocks which capture the entire maturity structure of oil futures are more representative of demand or supply shocks. Kilian (2008c) notes that oil price increases tend to cause recessions, but equivalent oil price decreases do not lead to economic expansions. He also provides evidence for asymmetries in the transmission of positive and negative oil price shocks. Here, in most cases the effects of functional oil price expectations shocks are found to be similar to those of supply shocks, i.e. they move inflation and output in opposite directions during both anchored and unanchored times.

Figure 6. Responses to standard shocks in unanchored times

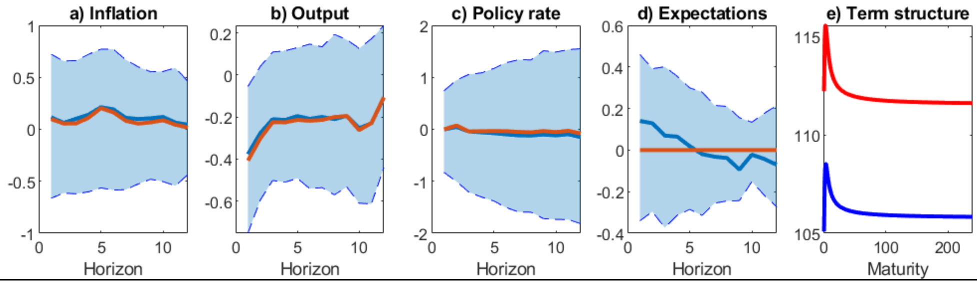
Panel A. August 1990



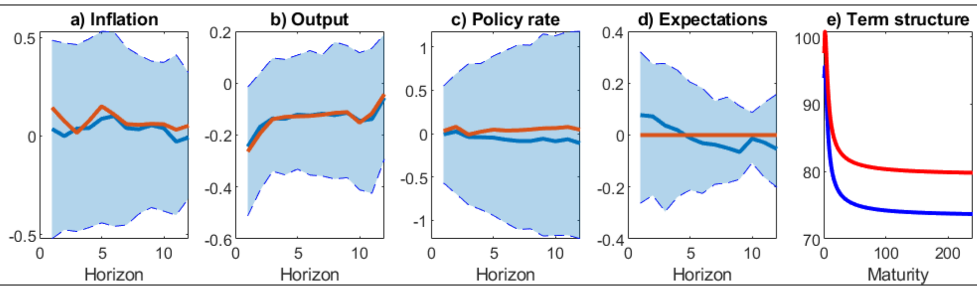
Panel B. January 2008



Panel C. April 2011



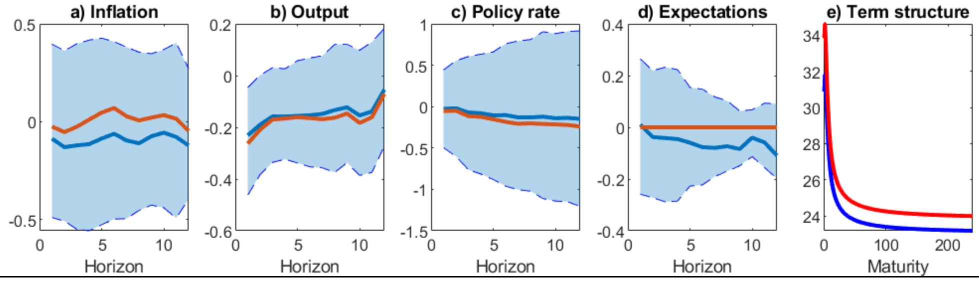
Panel D. March 2022



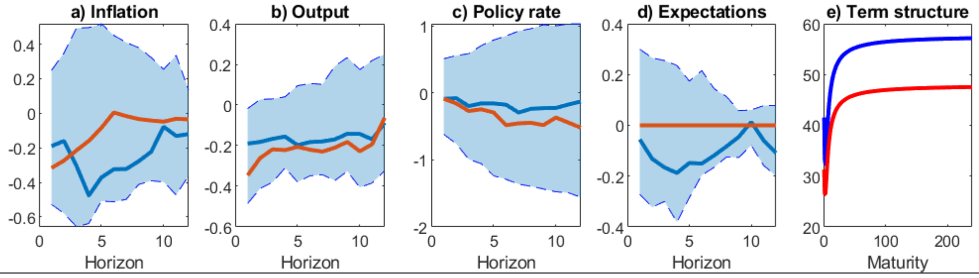
Notes: IRFs to functional oil price expectations shocks. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure 7. Responses to risk-adjusted shocks in anchored times

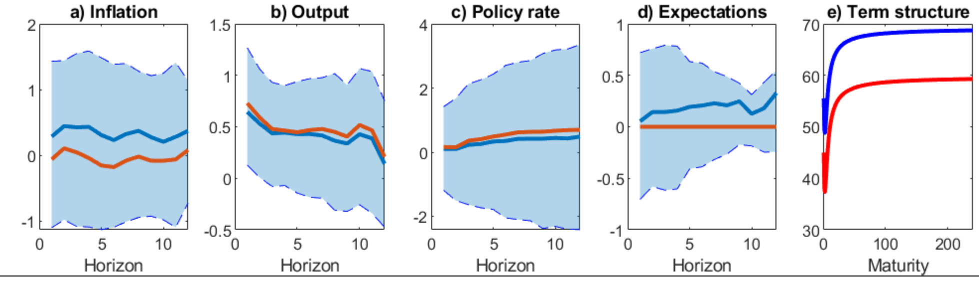
Panel A. March 2003



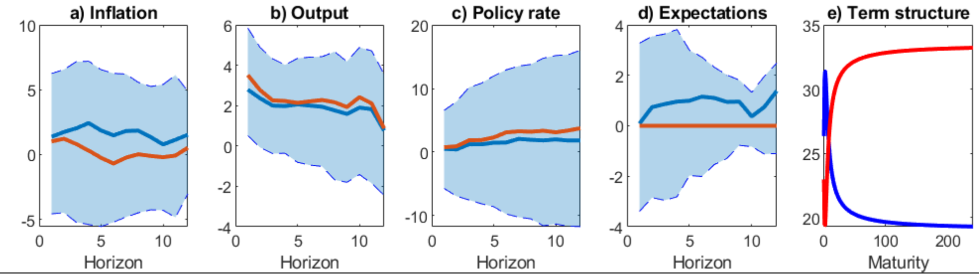
Panel B. December 2008



Panel C. December 2014



Panel D. April 2020



Notes: IRFs to risk-adjusted functional oil price expectations shocks. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

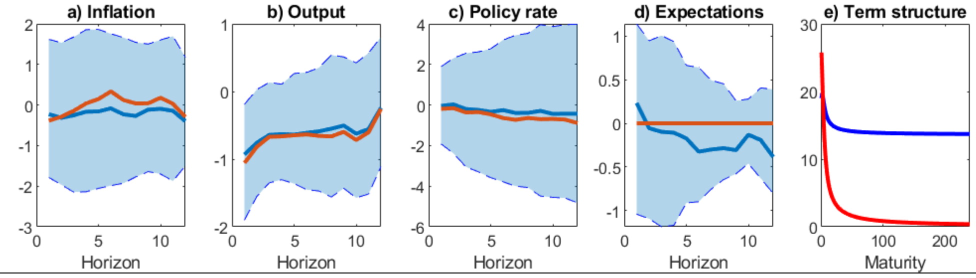
We now consider the risk-adjusted functional shocks and their second-round transmission through the inflation expectations channel during anchored (Figure 7) and unanchored times (Figure 8). It can be seen that there are some major differences compared to the unadjusted case. First, the response of inflation is much stronger for all events except August 1990, March

2003 and January 2008. The inflation and output responses do not seem to follow a consistent pattern in response to functional shocks of similar size and sign. For instance, in December 2008 (December 2014) output responded negatively (positively) to a similar negative functional oil price expectations shock. The inflation expectations response to the risk-adjusted shocks reflects the sign of the shocks, namely negative (positive) functional oil price expectations shocks which are represented by a downward (upward) shift in the oil futures term structure have a negative (positive) effect on inflation expectations resulting in deflationary (inflationary) second-round effects on inflation. In general, inflation expectations seem to respond more strongly to term structure shifts at the short rather than the long end. Further, there is a larger difference between the standard and counterfactual monetary policy response to functional oil price expectations shocks during the global financial crisis. As before, the policy rate response is contractionary (expansionary) in anchored (unanchored) times. One important difference in the risk-adjusted case is that the effects of functional oil price expectations shocks seem to reflect more closely those of demand (supply) shocks during anchored (unanchored) times.

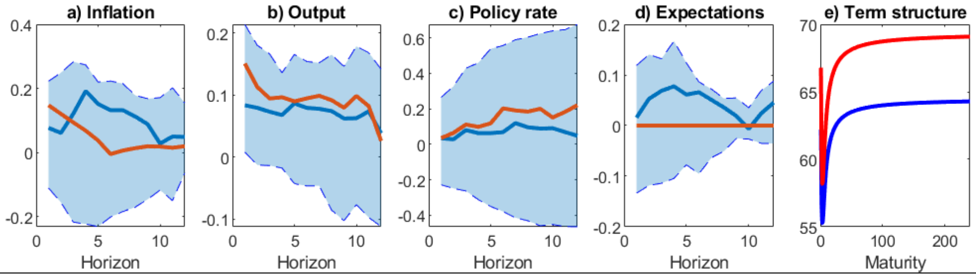
Next, we analyse in greater depth the response of inflation expectations to the individual functional shocks and the related second-round effects on inflation. There seem to be much stronger effects than in the case of the functional shocks derived from the standard term structure. The inflation response appears to track closely that of inflation expectations to the risk-adjusted functional oil price shocks, which indicates that the direction of the second-round movement in inflation is determined by the initial movement in inflation expectations. In the absence of second-round effects the inflation response to risk-adjusted functional oil price expectations shocks would have been close to zero in all cases. This suggests that oil price expectations influence inflation only because of the existence of second-round effects. More precisely, the latter are up to twice as large as the initial inflation expectations response. For instance, in April 2020 a one percentage point response of inflation expectations to a functional oil price expectations shock subsequently increased inflation by an additional 2.5 percentage points. These effects are also rather persistent over the response horizon. In contrast to the results reported by Wong (2015), which suggest an absence of second-round effects since the 1990s, we find evidence for significant ones during various episodes since that decade when using risk-adjusted functional oil price expectations shocks instead of real oil price shocks. In addition, while Wong (2015) concludes that inflation expectations are well-anchored in the US, our analysis of shocks during both anchored and unanchored times suggests that large second-round effects occur even when inflation expectations are anchored.

Figure 8. Responses to risk-adjusted shocks in unanchored times

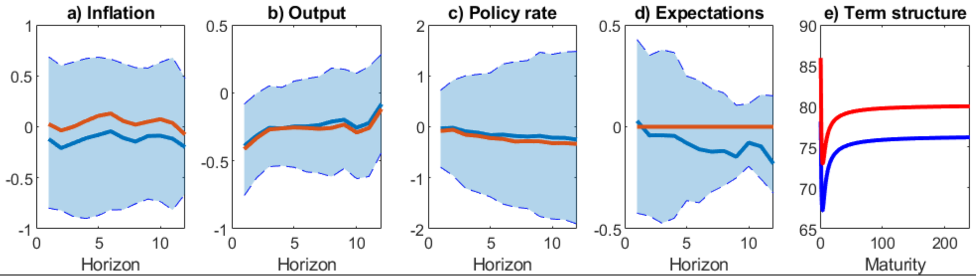
Panel A. August 1990



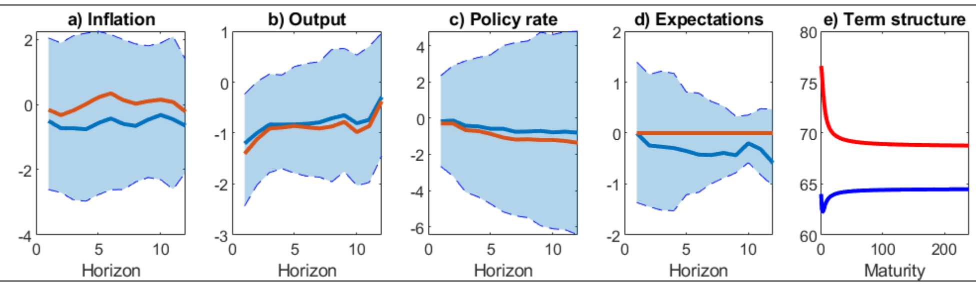
Panel B. January 2008



Panel C. April 2011



Panel D. March 2022



Notes: IRFs to risk-adjusted functional oil price expectations shocks. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

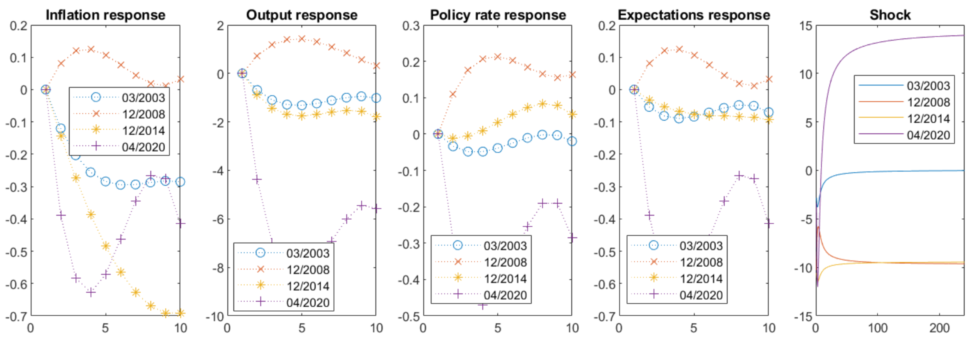
We also report results obtained by using core inflation (Appendix B). Now the second-round effects appear to be smaller for both the standard and risk-adjusted cases, although in some cases the direct effects are larger than for headline inflation. On the basis of the evidence presented in this section, we proceed with using only the risk-adjusted functional oil price expectations shocks for the subsequent analysis.

4.4 The role of inflation anchoring

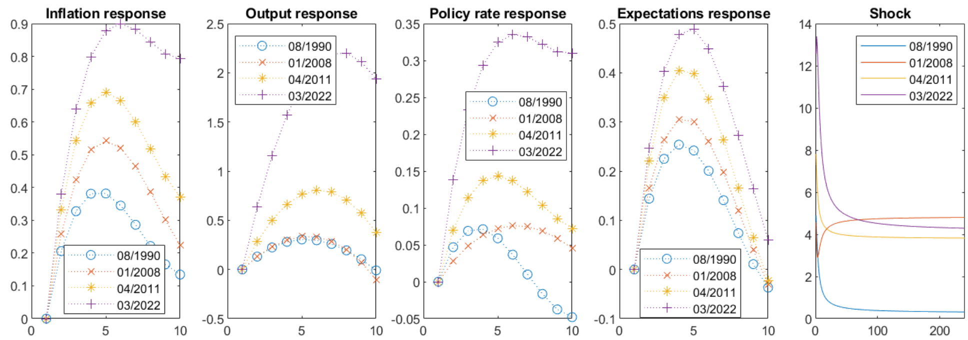
Existing papers on the transmission of oil and gas price shocks attribute to the anchoring of inflation expectations the absence of any response of inflation expectations and any propagation effects on inflation (Wong, 2015; Boeck and Zörner, 2023). To investigate these issues in greater depth in this section we account directly for the regime of inflation expectations anchoring using nonlinear functional local projections. This method also allows us to obtain evidence regarding the relative importance of the individual term structure factors as drivers of the response of the macroeconomic variables to the functional oil price expectations shocks.

Figure 9. Responses to risk-adjusted functional oil price expectations shocks

Panel A. Anchored regime



Panel B. Unanchored regime

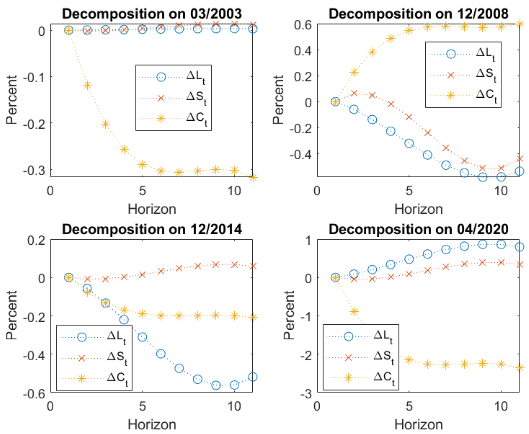


Notes: Responses to risk-adjusted functional oil price shocks using nonlinear functional local projections. The threshold variable indicates the degree of inflation expectations anchoring.

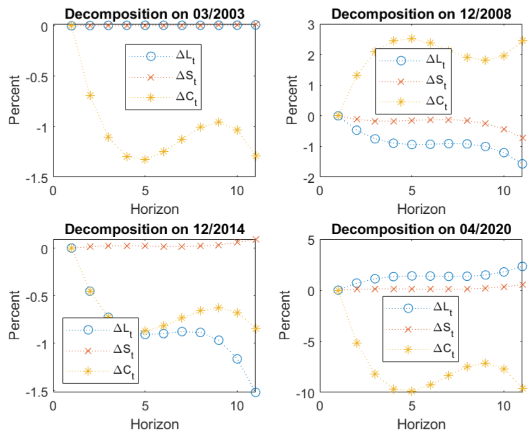
Figure 9 displays the IRFs obtained from nonlinear functional local projections for the two regimes of anchored and unanchored expectations. Inflation tends to respond negatively to risk-adjusted functional oil price expectations shocks in the anchored regime but positively in the unanchored one. The same holds for output and inflation expectations. While the response of the policy rate varies in the anchored regime, it is consistently positive in the unanchored regime. The size of the responses seems to reflect that of the shocks in all cases. Overall, these findings suggest that the extent to which inflation expectations are anchored matters greatly for the transmission of oil price expectations shocks. However, there are substantial differences in the contribution of the individual term structure factors as drivers of the responses.

Figure 10. Decomposition of IRFs to risk-adjusted shocks in the anchored regime

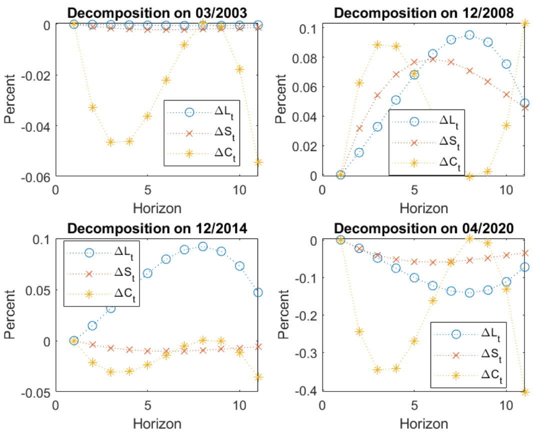
Panel A. Inflation



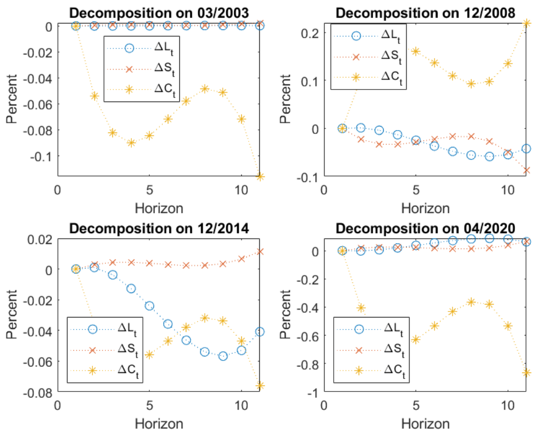
Panel B. Output



Panel C. Policy rate



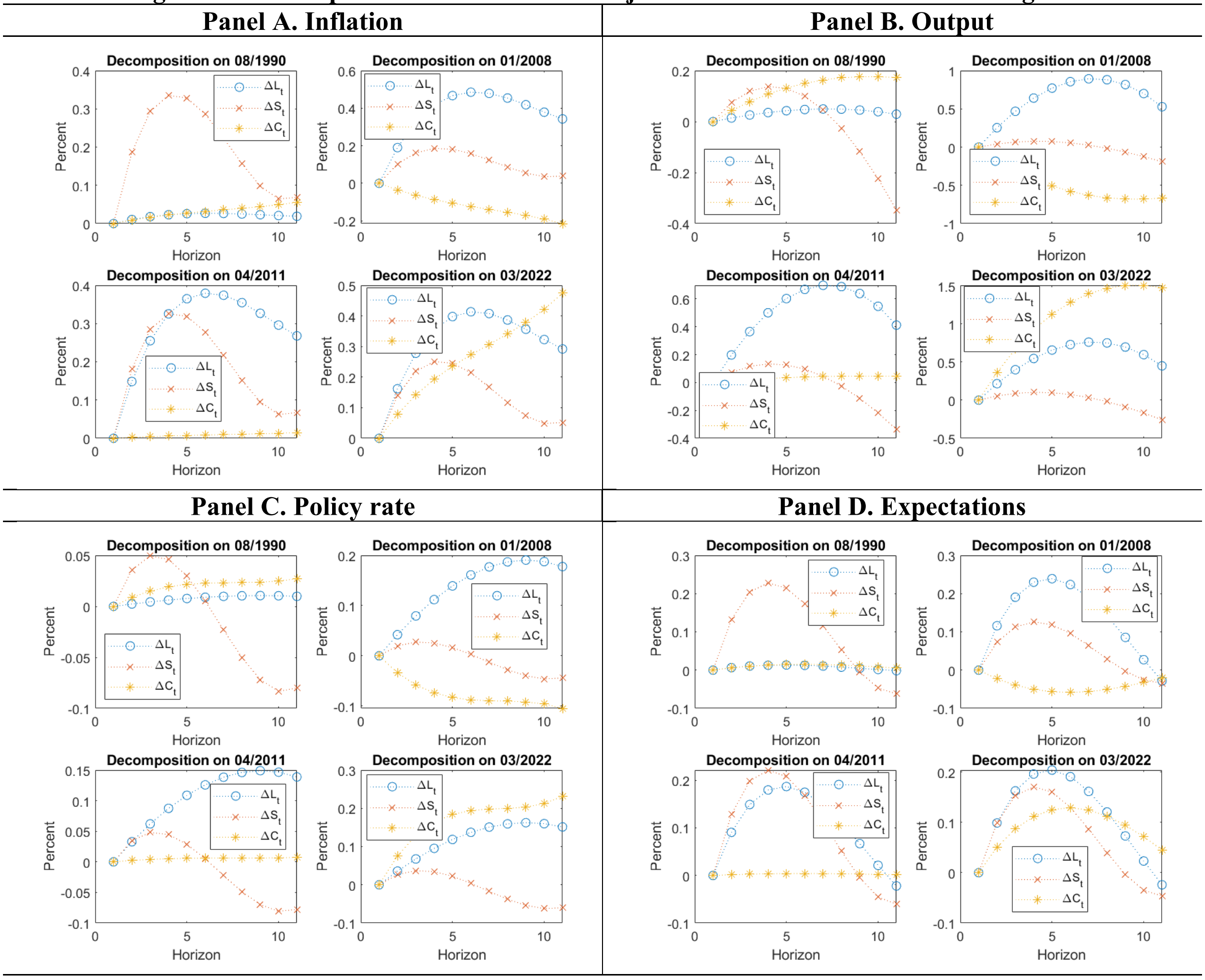
Panel D. Expectations



Notes: Decomposition of IRFs to risk-adjusted functional oil price expectations shocks from the nonlinar functional local projections.

Figures 10 and 11 show the results of the decomposition. The curvature factor appears to be the one driving most of the responses of all four macroeconomic variables in the anchored regime; instead, in the unanchored one the level and slope factors are more relevant. The curvature factor indicates the speed at which expectations in the oil futures market change, while the level and slope factors indicate changes in oil futures prices overall and at the short end. Given our interpretation of the term structure factors, it appears that when inflation expectations are anchored, inflation and inflation expectations only respond to shifts in the speed at which oil price expectations change. By contrast, when they are unanchored, inflation and inflation expectations respond to any shifts in oil futures prices, regardless of whether prices change more at the short end or equally across the entire term structure.

Figure 11. Decomposition of IRFs to risk-adjusted shocks in the unanchored regime



Notes: Decomposition of IRFs to risk-adjusted functional oil price expectations shocks from the nonlinar functional local projections.

These findings provide some valuable insights into the importance of inflation expectations anchoring, which seems to influence which information from the oil futures term structure agents take into account when forming inflation expectations. Overall, the obtained evidence suggests that the shape and shift of the entire risk-adjusted oil futures term structure matters for inflation, output, the policy rate and inflation expectations, which is an important feature that cannot be captured by scalar shocks.

5. Extensions

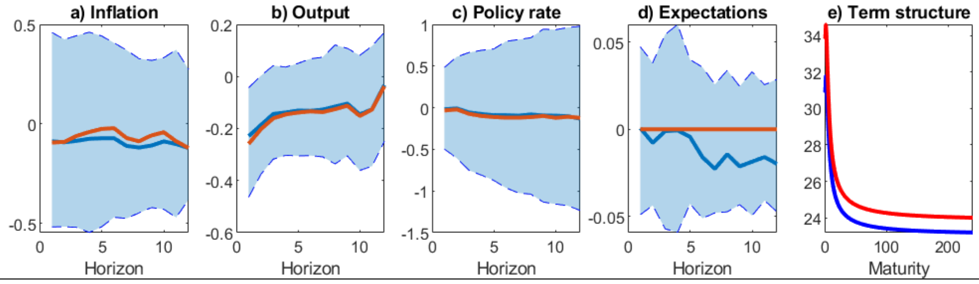
We extend the analysis in two ways. First, we consider different measures of inflation expectations, in particular long-term survey expectations as well as market expectations. One would expect that both are influenced by the oil futures term structure shifts, the former especially at long maturities, and the latter at all maturities. Second, we repeat the analysis using functional shocks based on Brent crude oil futures prices. In this case, we construct functional shocks from the risk-adjusted futures prices only.

5.1 Different measures of inflation expectations

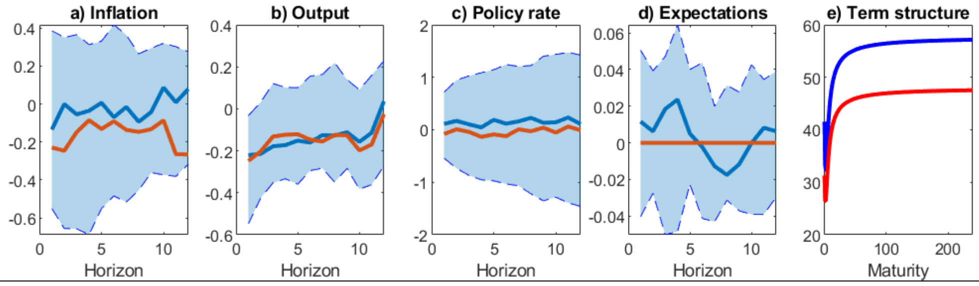
Figures 12 and 13 display the direct and second-round effects of risk-adjusted functional oil price expectations shocks during anchored and unanchored times, but this time with long-term survey expectations instead of short-term ones. Kilian and Zhou (2022b) suggest that oil price shocks do not have any impact on long-term household inflation expectations. Instead, we find that long-term expectations matter to some extent for the propagation of oil price expectations shocks to inflation. Compared to the baseline model with short-term expectations, however, the second-round effects are estimated to be much smaller, being on average only around half the size. The results using long-term survey expectations are consistent with previous findings that short-term inflation expectations matter more for inflation than long-term expectations (Fuhrer et al., 2012; Boeck and Zörner, 2023), but it appears that the latter are also relevant for transmitting functional oil price expectations shocks. Figures 14 and 15 display the results from the model with market expectations. Owing to the shorter data availability, we only report results after 2004. The evidence suggests the second-round effects are small in most cases and have similar patterns to those previously found using survey expectations.

Figure 12. Results using long-term expectations in anchored times

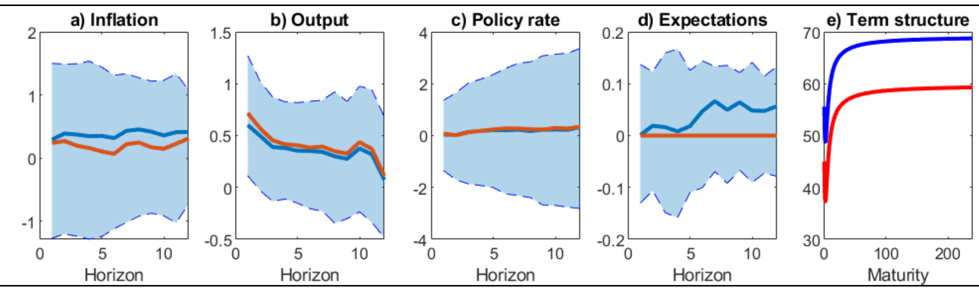
Panel A. March 2003



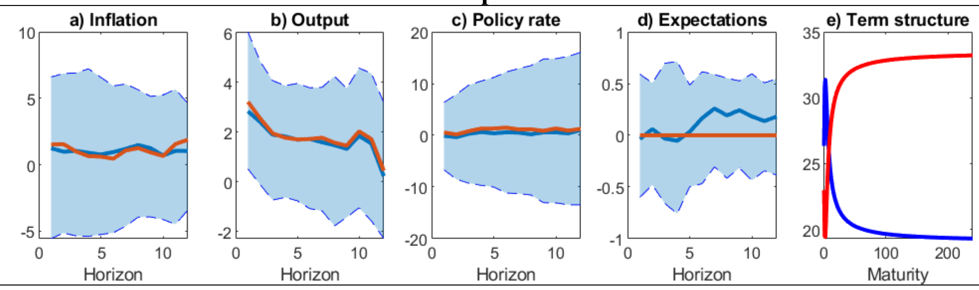
Panel B. December 2008



Panel C. December 2014



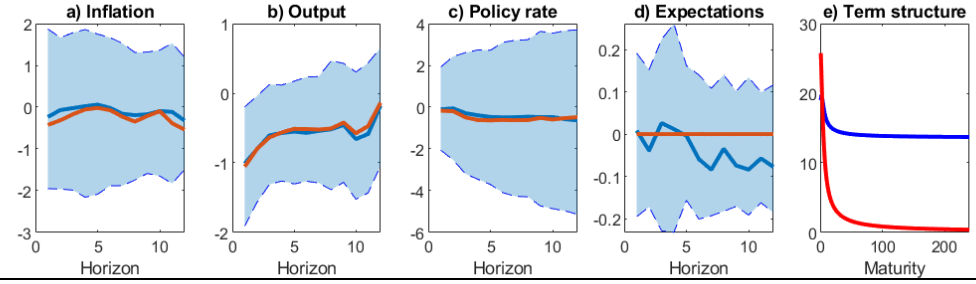
Panel D. April 2020



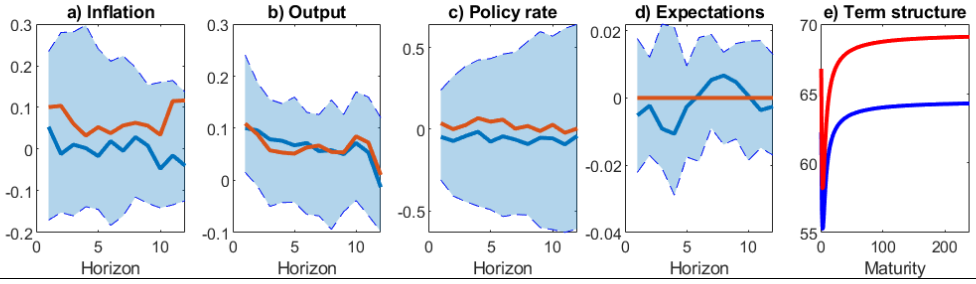
Notes: IRFs to risk-adjusted functional oil price expectations shocks from the model with long-term inflation expectations. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure 13. Results using long-term expectations in unanchored times

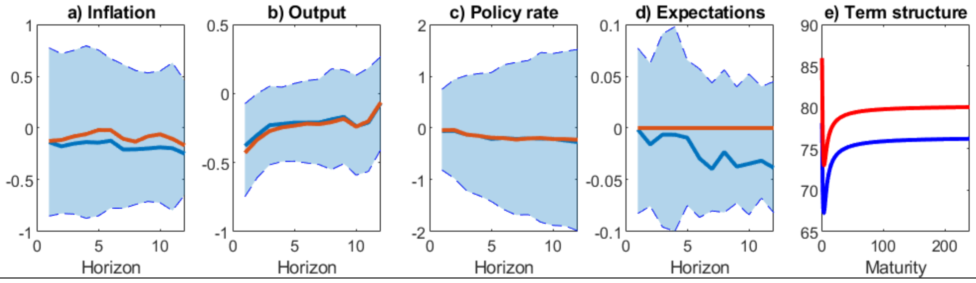
Panel A. August 1990



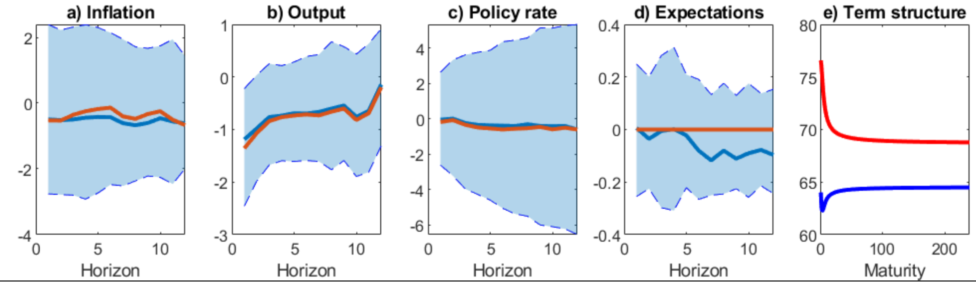
Panel B. January 2008



Panel C. April 2011



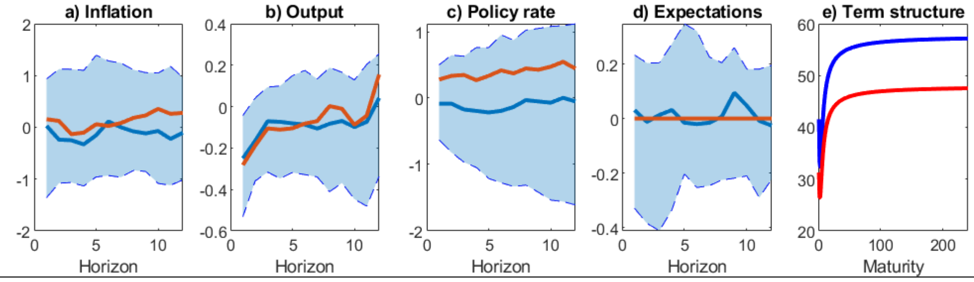
Panel D. March 2022



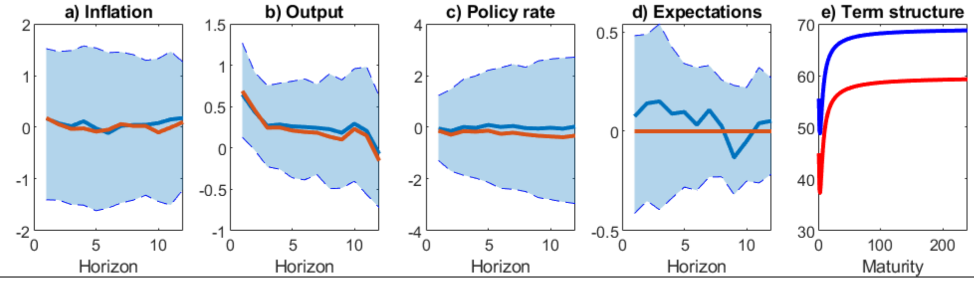
Notes: IRFs to risk-adjusted functional oil price expectations shocks from the model with long-term inflation expectations. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure 14. Results using market expectations in anchored times

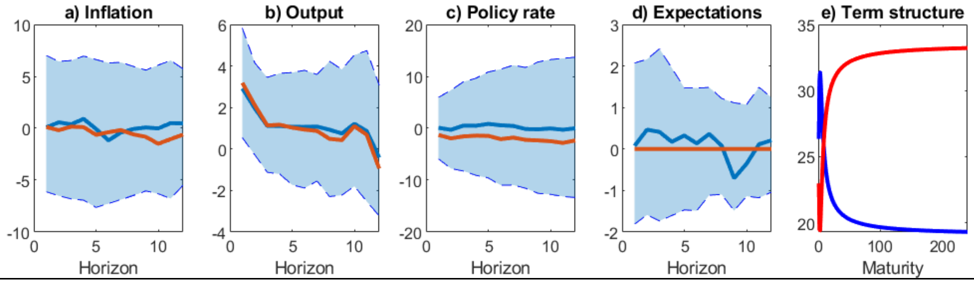
Panel A. December 2008



Panel B. December 2014

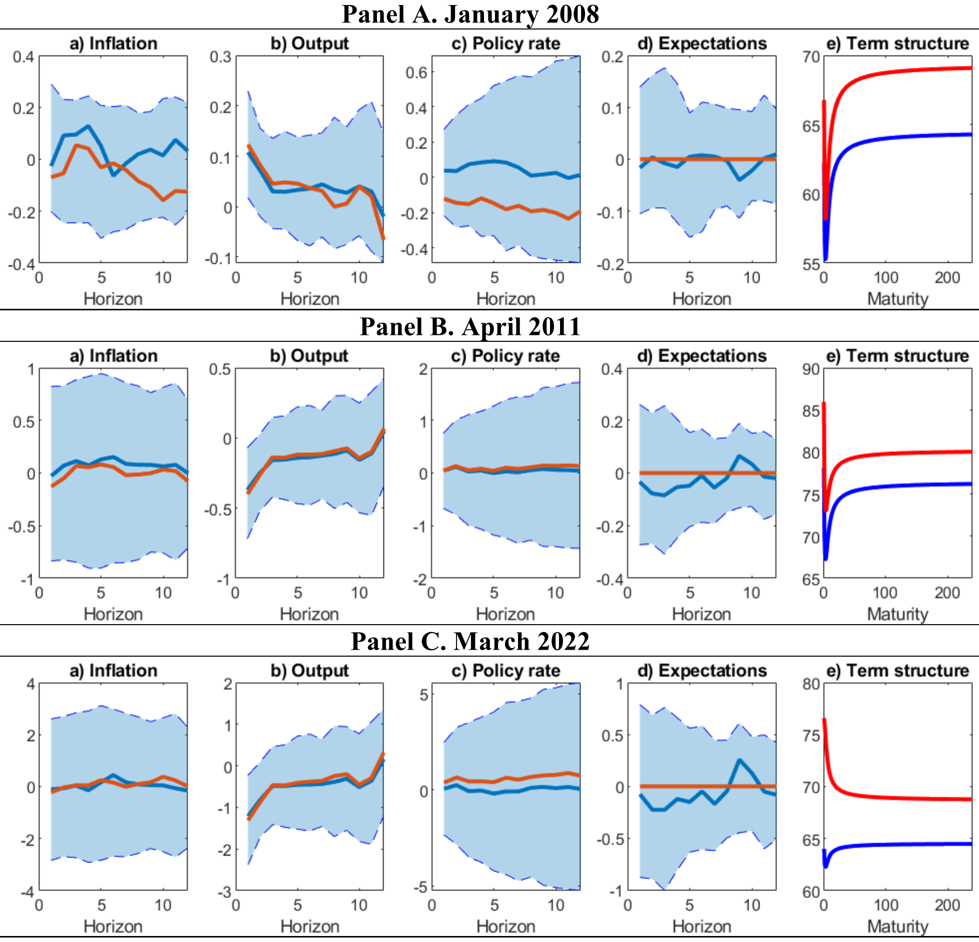


Panel C. April 2020



Notes: IRFs to risk-adjusted functional oil price expectations shocks from the model with market-based inflation expectations. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure 15. Results using market expectations in unanchored times



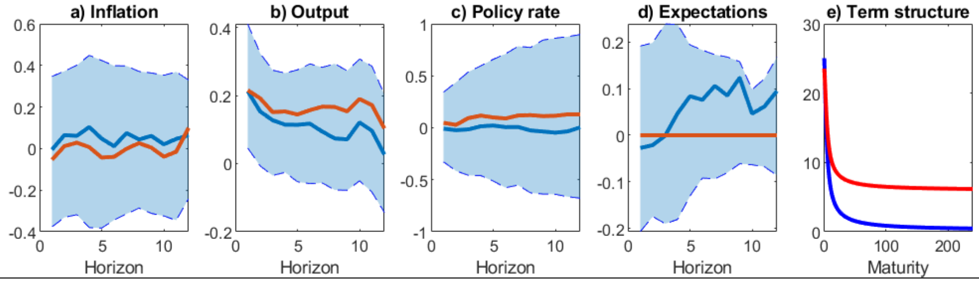
Notes: IRFs to risk-adjusted functional oil price expectations shocks from the model with market-based inflation expectations. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

5.2 Functional oil price expectations shocks using Brent crude oil futures prices

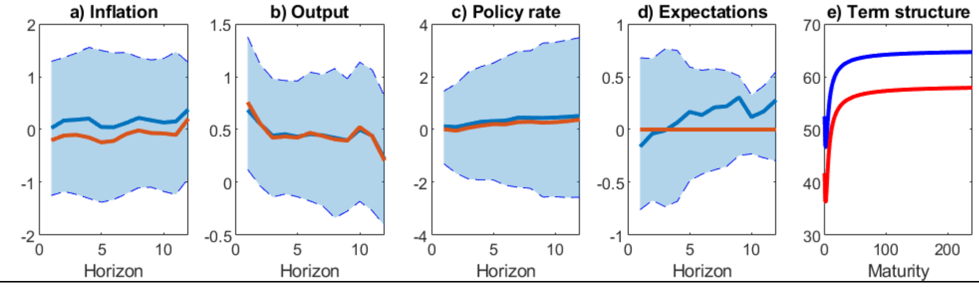
The spread between the WTI and Brent crude oil prices has been widening since 2011. The increased production of shale oil in the US resulted in WTI trading at a discount, which means that it is no longer regarded as representative of global oil prices. As a result, in recent years these have more frequently been measured using Brent crude oil prices (Baumeister and Kilian, 2016). Figures 16 and 17 show the responses to risk-adjusted functional oil price expectations shocks derived from the Brent crude oil futures term structure. The results are similar to those obtained from the model using WTI futures, which implies robustness of the baseline results.

Figure 16. Results using risk-adjusted Brent futures in anchored times

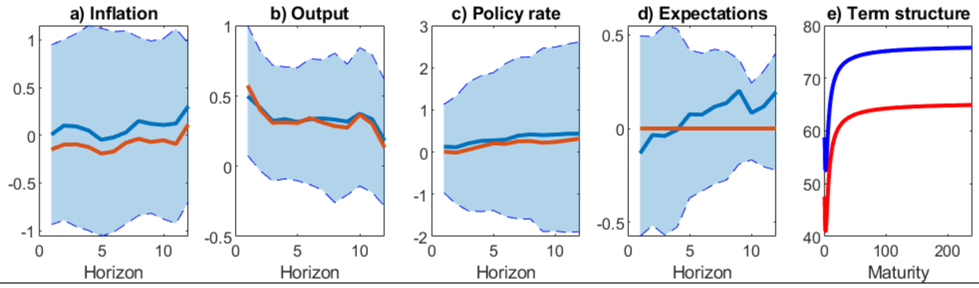
Panel A. March 2003



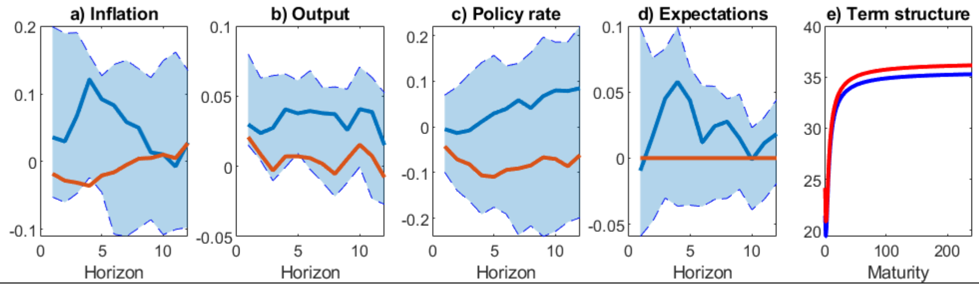
Panel B. December 2008



Panel C. December 2014



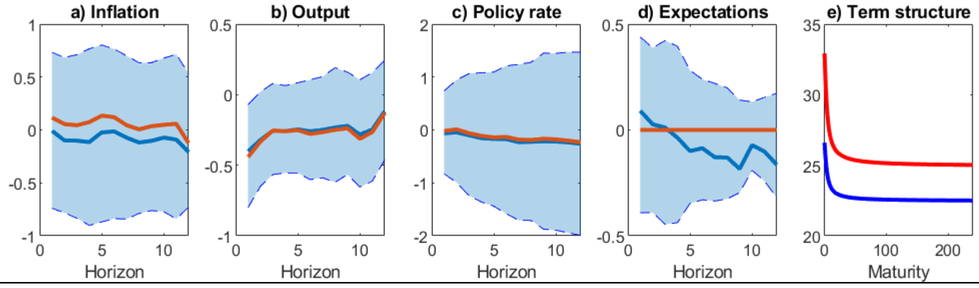
Panel D. April 2020



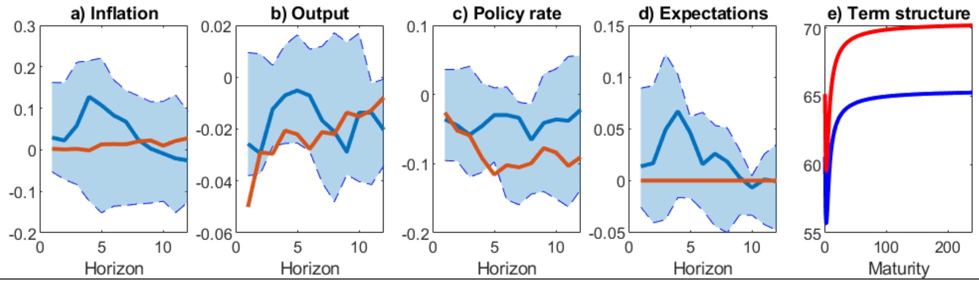
Notes: IRFs to risk-adjusted functional oil price expectations shocks derived from Brent futures. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure 17. Results using risk-adjusted Brent futures in unanchored times

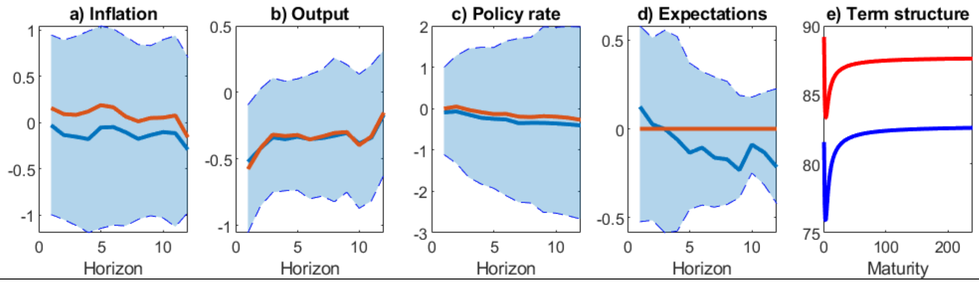
Panel A. August 1990



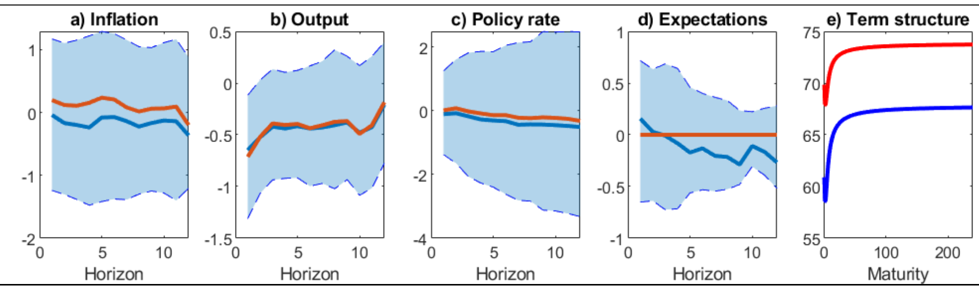
Panel B. January 2008



Panel C. April 2011



Panel D. March 2022



Notes: IRFs to risk-adjusted functional oil price expectations shocks derived from Brent futures. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

4. Conclusions

This paper investigates the effects of oil price expectations shocks on inflation and inflation expectations in the US. The analysis uses functional oil price expectations shocks derived from both the standard and the risk-adjusted WTI oil futures term structure, where the former can be interpreted as the oil price expectations of policymakers and the latter as those of financial market participants. Functional shocks capture simultaneous shifts in the short-, medium- and long-term term structure and therefore reflect changes in oil price expectations across all maturity horizons. These shocks are included in a VARX model with zero and sign restrictions to assess their effects on the US economy. Counterfactuals are then created by shutting off the inflation expectations response to the functional shocks in order to investigate their second-round effects on inflation. Next, nonlinear local projections are used to distinguish between different regimes of inflation expectations anchoring and to assess the contribution of the individual term structure factors to the macroeconomic responses to the functional oil price expectations shocks. Finally, the analysis is extended by using different measures of inflation expectations and by considering Brent crude oil futures prices.

The findings can be summarised as follows. First, the VARX estimates indicate that the functional oil price expectations shocks have significant effects on short-term survey inflation expectations, and small direct effects on inflation. Also, the responses are found to be larger in the case of the risk-adjusted rather than the standard term structure. Second, the results of the counterfactual analysis reveal that there are important second-round effects of functional oil price expectations shocks on inflation through the inflation expectations channel, especially in the risk-adjusted case which is more representative of the expectations of financial market participants. The evidence obtained for the latter suggests that, in the absence of propagation effects, functional oil price expectations shocks have no significant effects on inflation. Such propagation effects had not been detected by previous studies not using functional shocks (Wong, 2015). Third, the evidence obtained from the nonlinear functional local projections suggests that the macroeconomic responses to functional oil price expectations shocks are primarily driven by shifts in the curvature (level and slope) of the oil futures term structure during times when inflation expectations are anchored (unanchored). Therefore, it appears that the anchoring of inflation expectations matters for the transmission of the individual components of functional oil price expectations shocks. Fourth, the results of the extended analysis show that our findings are robust to the inflation expectations horizon and to whether one uses WTI or Brent crude oil futures prices.

On the whole, these findings provide some important insights into the often overlooked role of oil price expectations: these appear to have significant second-round effects on inflation to which central banks should pay attention to manage inflation expectations. Although the degree of anchoring does not seem to matter greatly for the size of the direct and second-round effects of oil price expectations shocks, it still has important implications. Specifically, it affects the type of information regarding the shift in the oil futures term structure which is most considered by agents when forming their inflation expectations, and also which term structure factor drives the second-round effects on inflation. Monetary authorities should take both into account in designing their communication strategy.

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Appendix A – Data appendix

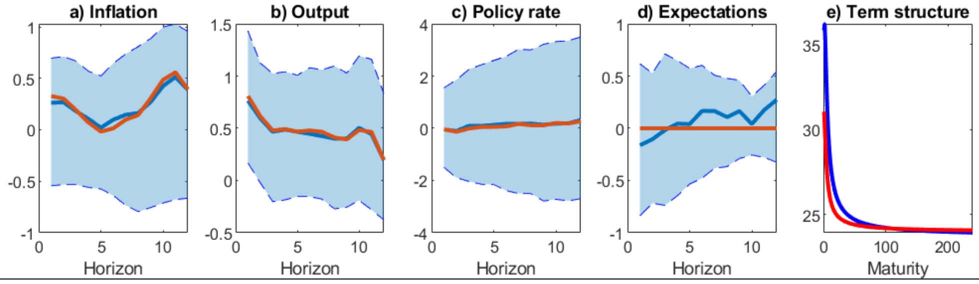
Table A1. Detailed futures data sources and description

Variable	**Ticker**	**Source**
WTI Crude Oil Generic Future – 1 month expiry	CL1	Bloomberg
WTI Crude Oil Generic Future – 2 months expiry	CL2	Bloomberg
WTI Crude Oil Generic Future – 3 months expiry	CL3	Bloomberg
WTI Crude Oil Generic Future – 4 months expiry	CL4	Bloomberg
WTI Crude Oil Generic Future – 5 months expiry	CL5	Bloomberg
WTI Crude Oil Generic Future – 6 months expiry	CL6	Bloomberg
WTI Crude Oil Generic Future – 7 months expiry	CL7	Bloomberg
WTI Crude Oil Generic Future – 8 months expiry	CL8	Bloomberg
WTI Crude Oil Generic Future – 9 months expiry	CL9	Bloomberg
WTI Crude Oil Generic Future – 12 months expiry	CL12	Bloomberg
WTI Crude Oil Generic Future – 18 months expiry	CL18	Bloomberg
WTI Crude Oil Generic Future – 24 months expiry	CL24	Bloomberg
Brent Crude Oil Generic Future – 1 month expiry	CO1	Bloomberg
Brent Crude Oil Generic Future – 2 months expiry	CO2	Bloomberg
Brent Crude Oil Generic Future – 3 months expiry	CO3	Bloomberg
Brent Crude Oil Generic Future – 4 months expiry	CO4	Bloomberg
Brent Crude Oil Generic Future – 5 months expiry	CO5	Bloomberg
Brent Crude Oil Generic Future – 6 months expiry	CO6	Bloomberg
Brent Crude Oil Generic Future – 7 months expiry	CO7	Bloomberg
Brent Crude Oil Generic Future – 8 months expiry	CO8	Bloomberg
Brent Crude Oil Generic Future – 9 months expiry	CO9	Bloomberg
Brent Crude Oil Generic Future – 12 months expiry	CO12	Bloomberg
Brent Crude Oil Generic Future – 18 months expiry	CO18	Bloomberg
Brent Crude Oil Generic Future – 24 months expiry	CO24	Bloomberg

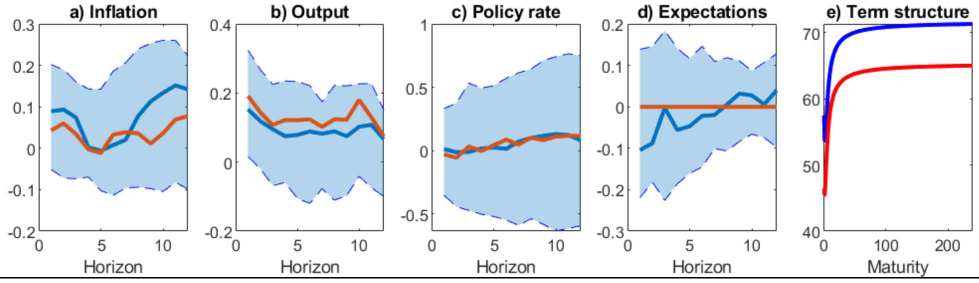
Appendix B – Additional baseline results using core inflation

Figure B1. Responses to standard shocks for key events in anchored times

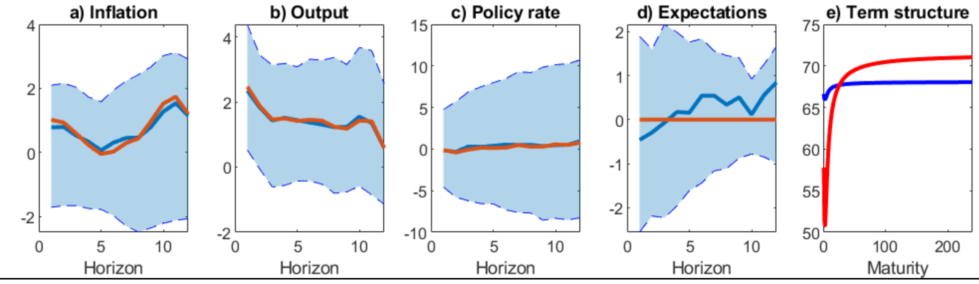
Panel A. March 2003



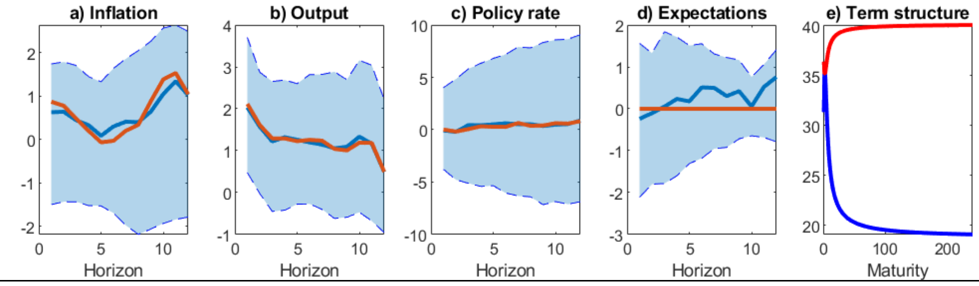
Panel B. December 2008



Panel C. December 2014



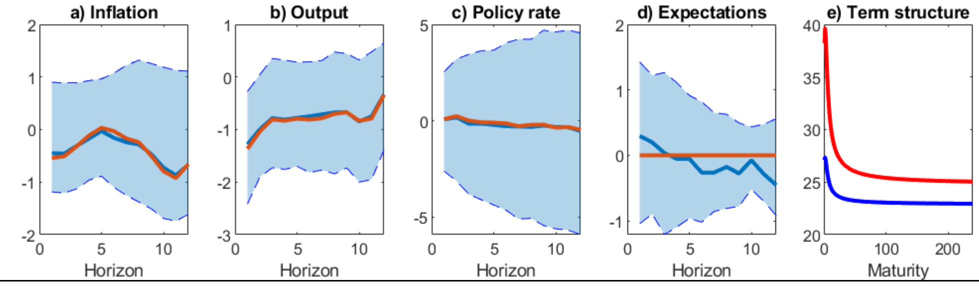
Panel D. April 2020



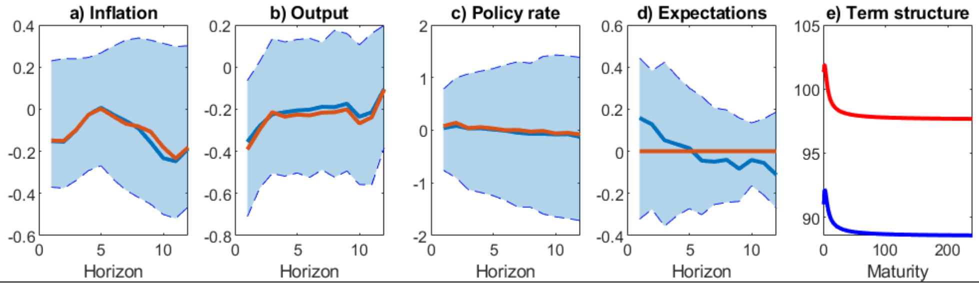
Notes: IRFs to functional oil price expectations shocks from the model with core inflation. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure B2. Responses to standard shocks for key events in unanchored times

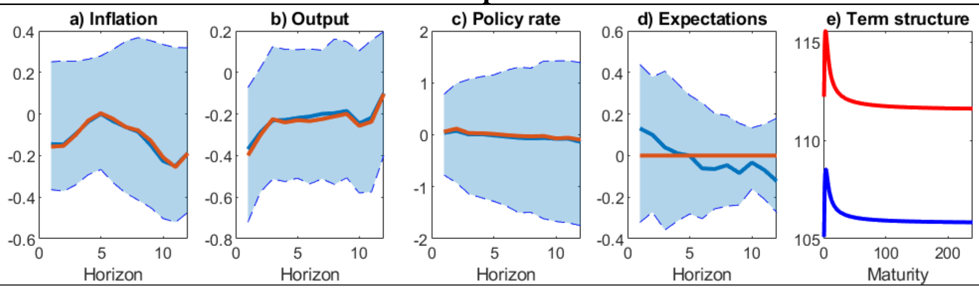
Panel A. August 1990



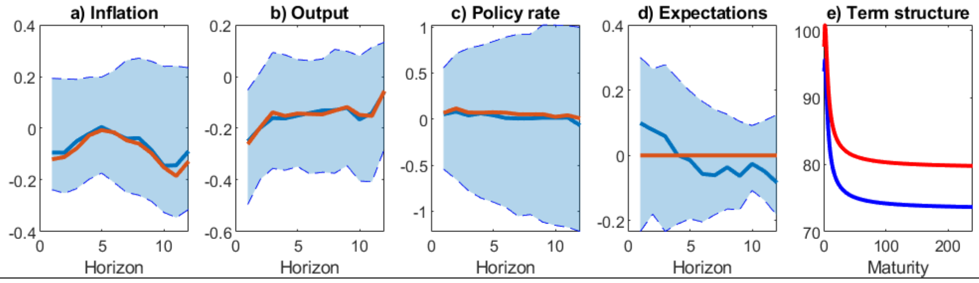
Panel B. January 2008



Panel C. April 2011



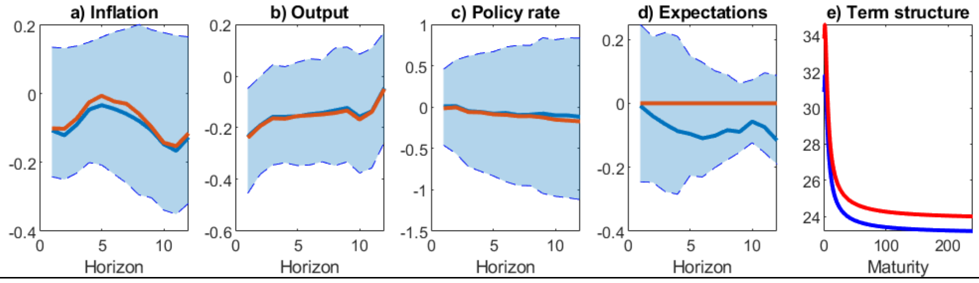
Panel D. March 2022



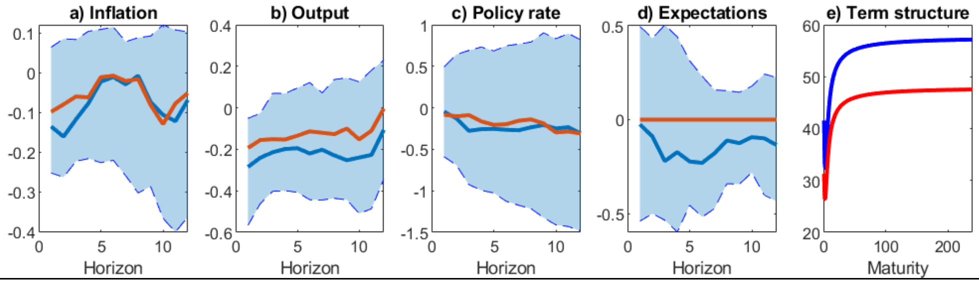
Notes: IRFs to functional oil price expectations shocks from the model with core inflation. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure B3. Responses to risk-adjusted shocks for key events in anchored times

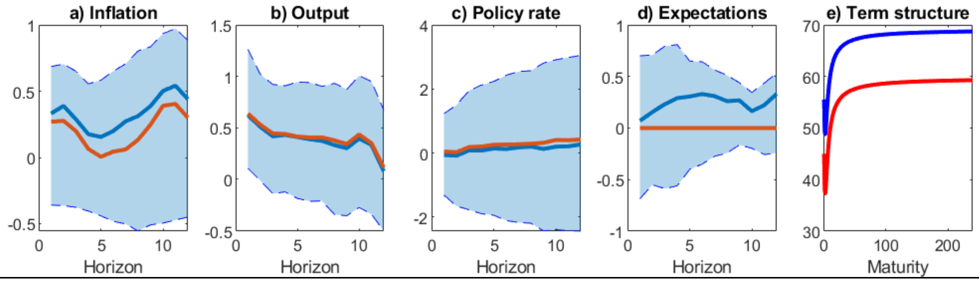
Panel A. March 2003



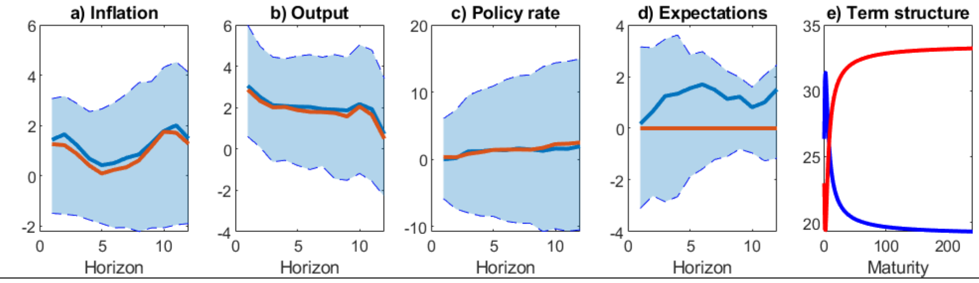
Panel B. December 2008



Panel C. December 2014



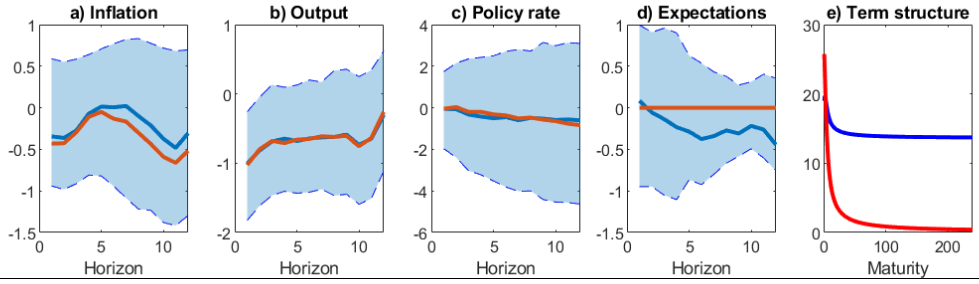
Panel D. April 2020



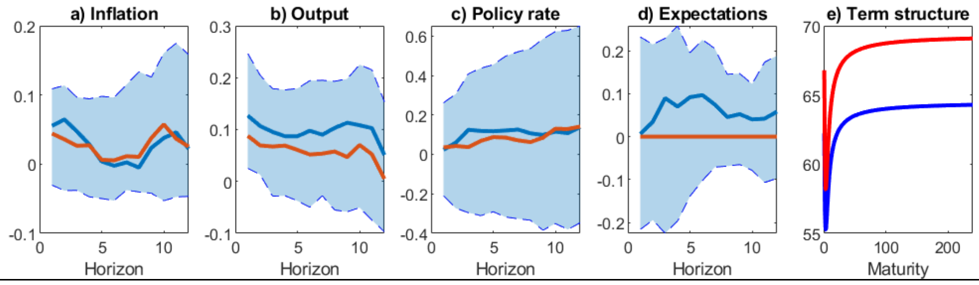
Notes: IRFs to risk-adjusted functional oil price expectations shocks from the model with core inflation. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.

Figure B4. Responses to risk-adjusted shocks for key events in unanchored times

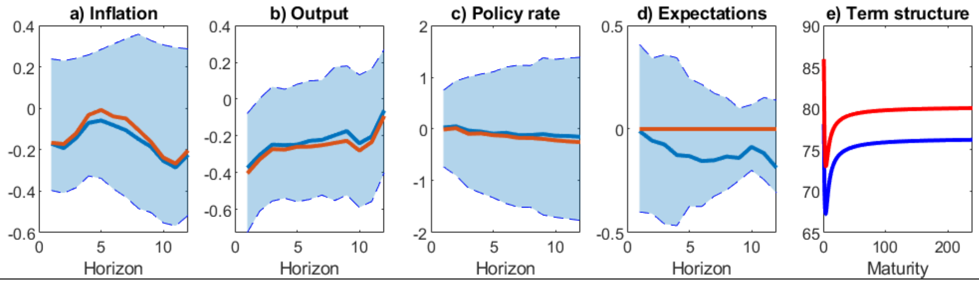
Panel A. August 1990



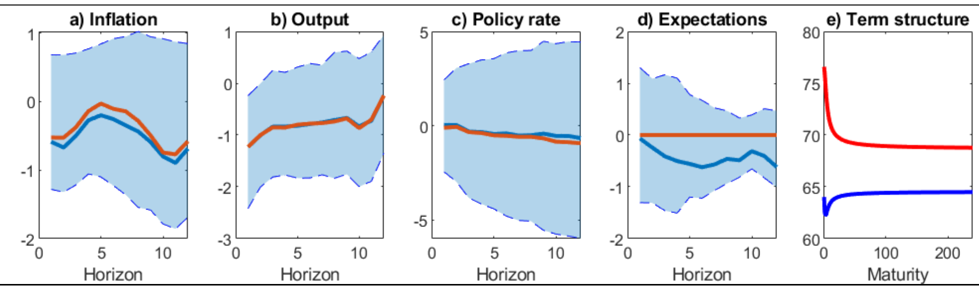
Panel B. January 2008



Panel C. April 2011



Panel D. March 2022



Notes: IRFs to risk-adjusted functional oil price expectations shocks from the model with core inflation. The solid blue line in graphs (a) – (d) in all panels depicts the median response to a functional oil price expectations shock, while the light shaded blue shaded area shows the 68% confidence bands. The orange solid line denotes the counterfactual with the expectations channel shut off. Graph (e) in all panels depicts the size of the functional oil price expectations shock where the solid blue line depicts the oil futures term structure before the shock and the solid red line after the shock.