WORKING paper

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Euro Area Monetary Policy Effects. Does the Shape of the Yield Curve Matter?*

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ABSTRACT

This paper investigates the effects of monetary policy in the euro area. We make three main contributions to the literature. First, we use the information from movements in the entire yield curve around monetary policy events to shed light on the efficacy of monetary policy. Second, we construct a novel and easy-to-update database of surprises based on intra-day quotes of Euro Area OIS forward rates and sovereign yields of France, Germany, Italy and Spain. Third, we show that the way conventional and unconventional monetary policy announcements shape expectations inherent in the term structure influences the response of key macroeconomic variables.

Keywords: Monetary Policy, Euro Area, Quantitative Easing

JEL classification: E50, E20, E37

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Non-Technical Summary

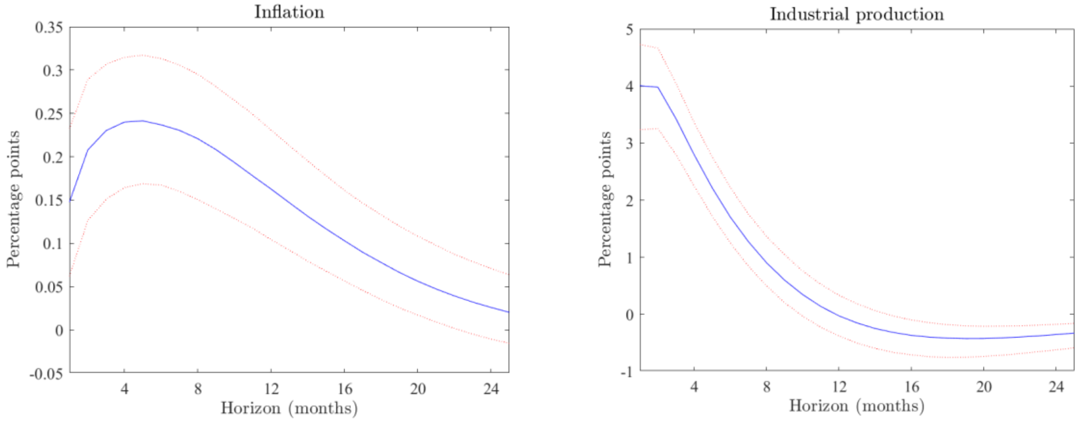
The monetary policy stance has been traditionally summarized by the (changes in the) short-term policy rate. However, the substantial use of unconventional monetary policy (UMP) tools by major central banks in the wake of the global financial crisis has induced the literature to broaden its perspective and consider a wider range of instruments, especially after short-term policy rates have hit their effective lower bound (ELB). Against this backdrop, this paper focuses on the effects of the euro area monetary policy focusing on exogenous shifts in the euro area yield curve (YC). In doing so, we classify such movements along the type of communication, e.g. conventional vs. unconventional monetary policy announcements, and the type of yield.

We contribute to the existing literature along several dimensions. First, we define a monetary policy shock as a "functional shock", i.e. a shift in the entire term structure of interest rates in a short window of time around central bank monetary policy announcement dates as measured by simultaneous changes of the yield curve at different maturities. This definition allows us to consider the impact on both short- and longer-term interest rates, which is needed to assess the effect of unconventional monetary policy measures or speeches. We identify monetary policy shocks directly as exogenous shifts in the entire term structure, without requiring any specific model (such as a factor model).

Second, we construct a novel database of surprises based on intra-day quotes of Euro Area OIS forward rates and sovereign yields of France, Germany, Italy and Spain. In our approach, surprise changes in both the risk-free and sovereign yield curves are identified via high-frequency movements of the whole term structure in a tight window of time around monetary policy events. We consider announcements during regular monetary policy meeting days, a few monetary policy announcements outside regular meetings and some important speeches given by the ECB President Mario Draghi.

Third, to the best of our knowledge, this is the first paper to systematically document the movements of the risk-free yield curve and of a euro area pseudo-government yield curve for different sets of monetary policy events. Notably, we perform an event study analysis using a narrative approach (tightening vs easing, conventional vs unconventional) to select the monetary policy events. We then provide an assessment of their impact on euro area output and inflation by means of a Functional Vector Autoregressive model with exogenous variables (Functional VARX) estimated over the period 2003:8-2021:3. The identification strategy is a high-frequency approach based on shifts in the short to medium-term portion of the OIS forward rates term structure around key monetary policy events. Overall, we find that the effects on output growth and inflation largely depend on the shape of the monetary policy shocks. We shed further light on this aspect by running some counterfactual exercises assuming shocks to the risk-free YC with comparable size but different shape.

Figure: Simulated effects of a uniform yield-curve level shock of -10 bps on inflation and output



Note: Dotted lines represent 68 percent confidence bands based on Monte Carlo simulations

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Effets de la politique monétaire dans la zone euro. La forme de la courbe des taux a-t-elle une importance ?

RÉSUMÉ

Ce document étudie les effets de la politique monétaire dans la zone euro. Nous apportons trois contributions principales à la littérature. Premièrement, nous utilisons les informations provenant des mouvements de l'ensemble de la courbe de rendement autour des événements de politique monétaire pour mettre en lumière l'efficacité de la politique monétaire. Deuxièmement, nous construisons une base de données inédite et facile à mettre à jour sur les surprises, à partir des cotations intra journalières des taux à terme OIS de la zone euro et des rendements souverains de la France, de l'Allemagne, de l'Italie et de l'Espagne. Troisièmement, nous montrons que la manière dont les annonces de politique monétaire conventionnelle et non conventionnelle façonnent les anticipations inhérentes à la structure des taux influence la réaction des principales variables macroéconomiques.

Mots-clés : politique monétaire, zone euro, assouplissement quantitatif

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1 Introduction

The monetary policy stance has been traditionally summarized by the (changes in the) short-term policy rate. However, the substantial use of unconventional monetary policy (UMP) tools by major central banks in the wake of the global financial crisis has induced the literature to broaden its perspective and consider a wider range of instruments, especially after short-term policy rates have hit their effective lower bound (ELB). Notably, the target of such instruments are interest rates at longer maturities. Forward guidance and asset purchases, for instance, explicitly aim at decreasing rates with medium- and long-term maturities, rather than short-term ones. It can be hence inferred that the entire term structure of interest rates contains valuable information on monetary policy and its effects on the economy, as highlighted by Inoue and Rossi (2021).

Against this backdrop, our paper focuses on the effects of the euro area monetary policy focusing on exogenous shifts in the euro area yield curve (YC). In doing so, we classify such movements along the type of communication, e.g. conventional vs. unconventional monetary policy announcements, and the type of yield. In particular, we consider the effects on a 'risk-free' euro area yield curve, based on Overnight Index Swaps (OIS) rates, as well as on a pseudo euro area government bond yield curve, computed as the GDP-weighted average of sovereign yields of the four biggest Eurozone members (France, Germany, Italy and Spain) at different maturities. We find that indeed a closer analysis of the latter curve is instrumental to disentangle between monetary policy actions that mainly affect the stance, as captured by the risk-free YC, and interventions that instead impact more the transmission of monetary policy in the euro area, as detected by movements in medium and long-term sovereign yields, via for instance a reduction in fragmentation or re-denomination risks. In what follows, we first perform a detailed event study analysis of major ECB monetary policy announcements up to March 2021; notably, we identify different types of events using a narrative approach. We then estimate the effects of a selection of these events on euro area macroeconomic aggregates by means of a novel Functional VARX model.

The paper makes several key contributions to the literature on euro area monetary policy. First, we define a monetary policy shock as a "functional shock" (Inoue and Rossi (2021)), that is a shift in the entire term structure of interest rates in a short window of time around central bank monetary policy announcement dates. This definition allows us to consider the impact on both short- and longer-term interest rates, which is needed to assess the effect of unconventional monetary policy measures or speeches. Thus, our paper contributes to the literature decomposing the euro area monetary policy shocks into a number of factors, each affecting a different portion of the yield curve (Krishnamurthy et al. (2017), and, in particular, for the euro area, Altavilla et al. (2019); Andrade and Ferroni (2021) among others). Altavilla et al. (2019) build on Gürkaynak et al. (2005) to investigate the effect of euro area monetary policy surprises on a large dataset of euro area financial variables. They find that three factors capture the lion's share of the variation in the risk-free euro area yield curve, with different factors associated to different monetary policy tools. Andrade and Ferroni (2021) instead distinguish between news on future macroeconomic conditions and news on future monetary policy shocks. We instead identify monetary policy shocks directly as exogenous shifts in the entire term structure, without requiring any specific model (such as a factor model). Differently from Inoue and Rossi (2021) we focus on the euro area and estimate the effects of the functional shock using a Functional Vector Autoregressive model with exogenous variables (Functional VARX) approach.

Second, by constructing a novel database of surprises based on intra-day quotes of Euro Area OIS forward rates and sovereign yields of France, Germany, Italy and Spain, we contribute to the literature that estimates monetary policy shocks by using high frequency data. In our approach, surprise changes in both the risk-free and sovereign yield curves are identified via high-frequency movements of the whole term structure in a tight window of time around monetary policy events. We consider announcements during regular monetary policy meeting days, a few monetary policy announcements outside regular meetings and some important speeches given by the ECB President Mario Draghi. For regular announcements, we construct surprises as in Altavilla et al. (2019). In particular, we compute surprises over the full monetary policy event, including both the press release and press conference windows. Differently from Altavilla et al. (2019), who use tick-by-tick quotes, we use minute-by-minute data from Reuters (Eikon). We show that differences between the two are negligible for the financial instruments included in both databases. This result has implications for applied work since minute-by-minute data are generally easier to obtain. For the other events outside regular Governing Council meeting days, which often occurred during weekends or outside trading hours, we use daily changes as estimates of monetary policy surprises.

Third, to the best of our knowledge, this is the first paper to systematically document the movements of the risk-free yield curve and of a euro area pseudo-government yield curve for different sets of monetary policy events. Notably, we perform an event study analysis using a narrative approach (tightening vs easing, conventional vs unconventional) to select the monetary policy events. We show that looking beyond the risk-free euro area yield curve, to a GDP-weighted sovereign yield curve, is critical to assessing the effectiveness of some unconventional monetary instruments introduced to preserve the uniqueness of euro area monetary policy. On the basis of the movements of the risk-free euro area yield curve, we then select a few key monetary policy events and provide an assessment of their impact on euro area output and inflation by means of the Functional VARX approach. Notably, we estimate the macroeconomic impact over the period 2003:8-2021:3 via a monthly VAR including a set of endogenous variables (euro area industrial production growth, euro area HICP inflation and the two-year OIS rate) as well as our monetary policy shocks as exogenous regressors. The identification strategy is a high-frequency approach based on shifts in the short to medium-term portion of the OIS forward rates term structure around key monetary policy events.

Our paper is also related to the literature that focuses on assessing the impact of monetary policy on economic activity. Among papers focusing on the effects of the euro area monetary policy, Andrade et al. (2016) show, for instance, that announcement of APP in January 2015 reduced long-term sovereign yields and feed this result into a stylized theoretical model to assess the consequences for macroeconomic aggregates. Gambetti and Musso (2020) assess the effect of the APP announcements on financial markets and euro area economic activity and inflation using a time-varying parameter VAR model; the authors find that effect of APP on the macroeconomic variables is sizeable. Rostagno et al.

(2021) identify the effect of unconventional measures using an event study with forward curve counterfactuals. They provide empirical evidence on the efficacy of unconventional monetary policies to stabilize output and inflation when the main policy rate is negative. Badinger and Schiman (2023) combine a narrative approach with high frequency movements of short-term OIS rates to identify euro area monetary policy shocks. They estimate a structural VAR model and show significant effects of monetary policy shocks on a range of macroeconomic variables. Our work differs from these papers across several dimensions, from the empirical methodology used to the selection of the events considered and the definition and identification of monetary policy shocks. It is worth noticing that, differently from a conventional monetary policy shock identified through the change in the short interest rate, the existing literature does not provide a clear guidance on how simultaneous shocks to yields of different maturities should be expected to affect inflation and output.

A short preview of the results of our event study analysis of monetary policy announcements is as follows. For the conventional monetary policy period before the global financial crisis (GFC): i) easing and tightening announcements generated overall very little surprises to the risk-free YC. Some exceptions are announcements at the start of the easing cycle in 2001, when the ECB decided to cut rates more aggressively by 50 bps; ii) movements in the GDP-weighted YC at long maturities are overall modest in size and smaller than those at shorter maturities, in line with the conventional nature of these monetary policy decisions. Looking at the post-GFC period and at both conventional and some unconventional announcements, we show that: i) surprises in the risk-free YC at short maturities following conventional announcements tend to be high at the beginning of each easing cycle but, along the cycle, markets seem to largely incorporate monetary policy movements in advance; ii) overall, those conventional events did not substantially move the GDP-weighted YC at medium and long maturities; iii) the announcements of four important unconventional tools introduced by the ECB between 2010 and 2020 had a strong negative impact on the GDP-weighted YC at medium and/or long maturities. Instead, they only had small effects on the risk-free YC and often on the positive side.

This empirical evidence has several implications for policy makers and researchers analysing the effects of monetary policy shocks. In particular, we show that similar announcements can lead to quite disparate effects on the euro area yield curves, both with respect to i) a risk-free vs. a riskier sovereign yield curve and ii) the shape of a given YC. The first finding is not surprising as several of the analysed unconventional tools have been introduced by the ECB to reduce fragmentation or redenomination risks to the euro area, or in other terms to ensure a smooth and even transmission of monetary policy in the area. Hence, they operated mainly through a reduction in sovereign credit risk premia with small or no effect on the stance, proxied by the risk-free YC. The second finding can be rationalized in several ways. A large literature looks at potential information effects in monetary policy surprises that, if not properly identified, may influence the effect of a given monetary policy shock on financial and macroeconomic variables (Nakamura and Steinsson (2018); Jarociński and Karadi (2020); Miranda-Agrippino and Ricco (2021); Andrade and Ferroni (2021)). Even without assuming that an information effect blurs the monetary policy shock, different YC responses to similar announcements can be due to: i) different ex-ante expectations of financial markets on similar or identical monetary policy decisions, and/or ii) anticipation of some monetary policy decisions by central bank officials, e.g. via speeches, whereby some decisions are priced in interest rates far in advance by financial markets (Istrefi et al. (2022)).

Results from the Functional VARX model point to effects on output growth and inflation that largely depend on the shape of the monetary policy shocks. A counterfactual exercise, based on the estimated parameters of the model and using comparable (in size) simulated functional shocks, shows several interesting results. When looking at fully contractionary/expansionary shocks (defined as positive/negative changes of the OIS yield curve across all maturities), we find the shocks entailing the biggest decreases/increases in inflation are those where changes in the yield curve are upward/downward sloping, i.e. those leading to more pronounced movements at the longer-end of the yield curve. The effects on industrial production are instead very similar across the shocks. When looking at mixed functional shocks, i.e. shocks designed to be comparable in size but characterized by a different sign at the short vs. the longer end of the OIS curve, results point to different impulse responses depending on the shape of the shock. Again, the behaviour of inflation is most influenced by longer-term changes in the yield curve. However, depending on the shape of the yield curve shock, the initial effect of a cumulatively expansionary shock can cause inflation to decline. This is the case for cuts in short-term rates offset by increases at the longer end. This analysis highlights that it is not enough to look only at the reaction of the short end of the yield curve to identify the effect of monetary policy shocks.

The paper is organized as follow: in Section 2, we detail the methodology used to construct our dataset of monetary policy surprises and provide some stylized facts, including a comparison with the dataset of Altavilla et al. (2019). Section 3 presents the event study analysis, where we focus on the behavior of the euro area risk-free and GDP-weighted sovereign yield curves around different sets of monetary policy announcements. Section 4 describes the empirical model used to assess the effect of a selection of monetary policy announcements on the euro area macroeconomy and discusses the results. Section 5 concludes.

2 Data and construction of euro area monetary policy surprises

Our first contribution is to construct a dataset of euro area monetary policy surprises to study high frequency movements of the euro area yield curves around ECB monetary policy events. In this section, we provide both an overview of the financial data used in the paper as well as details on the construction of our dataset of monetary policy surprises. Taking Altavilla et al. (2019) as a benchmark, we also describe similarities and differences between our dataset and theirs.

2.1 Financial Data

We collect daily and intra-daily data to construct monetary policy surprises around different monetary policy events – all ECB Governing Council Meetings from January 1999 to March 2021 as well as other important monetary policy announcements outside regular meetings and a few speeches by the ECB President Draghi. These surprises are then used to identify monetary policy shocks from yield curve movements around those events. Specifically, we obtained minute-by-minute quotes from Reuters (Eikon) and daily quotes from Bloomberg for the euro area OIS forward rates (Eonia Overnight Index Swaps) and the sovereign yields of Germany, France, Italy, and Spain. We take maturities from one month to ten years for OIS rates and from three months to ten years for sovereign yields. To compute GDP-weighted sovereign yields, we use annual nominal GDP series taken from the ECB's Statistical data warehouse (SDW).

Table 1 details the available starting date of minute-by-minute quotes for each each financial instrument. In particular, while short maturities for OIS rates are available since 1999 (September 2002 for the 3-year maturity), longer maturities (five to ten years) data only start in June 2011. For sovereign yields, the opposite is generally true, while short maturities (three and six months in particular) are often available only in mid to late 2000, depending on the selected country, longer maturities (from two year onwards) are available since the beginning of the sample. The last observation in our database is March 2021, for all yields and maturities.

Table 1: Availability of high frequency data — starting month and year

	1M	3M	6M	1Y	2Y	3Y	5Y	7Y	10Y
DE	NaN	Oct-2005	Oct-2005	Apr-2000	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999
FR	NaN	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999
IT	NaN	Jul-2009	Jul-2009	Jul-2009	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999
ES	NaN	Oct-2010	Oct-2010	Oct-2010	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Jan-1999
OIS	Jan-1999	Jan-1999	Jan-1999	Jan-1999	Nov-1999	Sep-2002	Jun-2011	Jun-2011	Jun-2011

Notes: The table shows the starting month and year from which minute-by-minute quotes of the respective financial instrument are available in our database. DE, FR, IT, and ES denote the sovereign yields, at maturities indicated by the column names, for Germany, France, Italy, and Spain. OIS are Eonia Overnight Index Swaps.

2.2 High Frequency Monetary Policy Surprises

In the construction of the high-frequency surprises, we follow the methodology of Altavilla et al. (2019) when applicable. Differently from their paper, our database consists of minute-by-minute quotes, not tick-by-tick ones. Hence, we proceed as follows. We clean the quotes for misquotes and outliers on the days of the monetary policy events that we consider. Misquotes are defined by quotes with a negative bid-ask spread or a bid-ask spread that is 50 times larger than the median bid-ask spread on that day; we additionally identify and clean a few hand-selected misquote instances where, for example, the quotes changed by several hundred basis points (bps) from one minute to the other.

We construct surprises over the full monetary policy event window, as in Altavilla et al. (2019) as follows. Typically, after an ECB Governing Council (GC) meeting, there is a press release published at 1.45 pm, which contains the monetary policy decisions. This is followed by a press conference at 2.30 pm, which lasts for about an hour and includes time for Q&A with financial journalists.[1] The overall monetary event surprises are computed as the difference between the median quote from 1.25pm to 1.35pm and the median quote from 3.40 to 3.50pm, i.e. covering the entire time period from before the press release to after the end of the press conference.

We define the beginning and end of the time windows of press releases or press conferences that were published or occurred at a different time by following the same logic explained above.

Working with minute-by-minute quotes means that there can be at most 11 quotes for the pre-event window from 1.25pm to 1.35pm, which we use to compute the pre-event median. Sometimes there are few or no quotes in the time window from 1.25pm to 1.35pm. Therefore, if Q denotes the number of quotes available between 1.25pm to 1.35pm, then $X = 11 - Q$ denotes the number of missing quotes. If $Q < 4$, i.e. if there are fewer than four quotes in the pre-event window, we search in the two hours before 1.25pm and take at most the X last quotes before 1.25pm that are available. If $Q \geq 4$, i.e. if there are four or more quotes in the 1.25pm to 1.35pm window, we take the median of these quotes and do not search for additional quotes in the time period before 1.25pm.

We proceed similarly for the post-event window. If Q denotes the number of quotes available between 3.40pm to 3.50pm, then $X = 11 - Q$ denotes the number of missing quotes. If $Q < 4$, we look in the two hours after 3.50pm and take at most the X first

[1] Note that for several ECB Governing Council meetings, these times are different and we use the comprehensive list of ECB GC press release and press conference times provided in the Appendix of Altavilla et al. (2019) to account for those exceptions. Notice also that the time of the press release and press conference has changed since June 2022.

quotes after 3.50pm that are available. If $Q \geq 4$, i.e. if there are four or more quotes in the 3.40pm to 3.50pm window, we take the median of these quotes and do not search for additional quotes in the time period after 3.50pm.

Table 2 provides details on the other events that are included in our event study analysis. In particular, we consider five monetary policy related announcements that occurred outside regular meetings' days. Three refer to ECB asset purchase programs - the announcement and the activation of the Securities Markets Programme (SMP) in May 2010 and August 2011 and the announcement of the Pandemic Emergency Purchase Programme (PEPP) in March 2020 - and two to decisions on the Eurosystem collateral framework taken in April 2020 during the pandemic crisis. We then consider six speeches delivered by President Draghi over his presidency. We follow Rostagno et al. (2021) for the choice of five key speeches that have had significant effects on financial markets from 2014 to 2019, to which we add the famous "Whatever it takes" speech given in London in July 2012.

Table 2: Other announcements outside regular monetary policy meetings

Date	***Announcement***	***Day of the week/CET time***	***Press release***
5/10/2010	SMP announcement	Monday/morning	Link SMP1
8/7/2011	SMP activation	Sunday	Link SMP2
3/18/2020	PEPP annoncement	Wednesday/23:00	Link PEPP
4/7/2020	Collateral measure	Tuesday/late afternoon	Link Collateral1
4/22/2020	Collateral measure	Wednesday/evening	Link Collateral2
	Speeches	***Day of the week/CET time***	
7/26/2012	Draghi speaks at Global Investment Forum	Thursday/11:15	
8/22/2014	Draghi speaks at Fed Jackson Hole Symposium	Friday/20:30	
12/4/2015	Draghi speaks in New York	Friday/18:20	
6/27/2017	Draghi speaks in Sintra, Portugal	Tuesday/10:00	
3/27/2019	Draghi speaks in Frankfurt (ECB Watchers)	Wednesday/09:00	
6/18/2019	Draghi speaks in Sintra, Portugal	Tuesday/10:00	

Notes: The table reports the events outside regular monetary policy meetings' days included in our dataset, as well as the day of the week in which the event occurred. For the speaking events, it also indicates the CET time reported in Bloomberg.

These announcements occurred mostly outside Central European Time (CET) trading hours, either over weekends or late in the evening. For speeches delivered in the morning, a precise timing of the event, besides the time reported in Bloomberg, and of their impact on OIS and sovereign yields is more difficult than for the case of announcements during regular monetary policy meetings' days. For this reason, we decided to treat all these additional events in the same way by computing daily changes to identify monetary policy surprises. In particular, we compute the surprises as T - (T-1) end of the day quotes where T is the day of the event for events occurred in a week day and during trading hours, or the first trading day after the event in the case of events occurred after market close or during weekends. Accordingly, in this latter case, (T-1) is the day of the event (if a week day) or the previous Friday if the event occurred during the weekend.

2.3 Our Monetary Policy Surprises Versus Altavilla et al. (2019): A Comparison

We compare our monetary policy surprises during regular Governing Council meetings' days – computed using the minute-by-minute quotes in combination with the procedure outlined above – and the surprises of Altavilla et al. (2019), which are computed from tick-by-tick quotes. Compared to Altavilla et al. (2019), our database also contains surprises for the short-term yields of Germany, France, Italy, and Spain, when available.

Table 3 shows three measures of correlation. All them are very close or equal to 1 for all comparable instruments and maturities, i.e., minute-by-minute data leads to virtually identical surprises as tick-by-tick data.[2] Since minute-by-minute data are easier to obtain and to work with than tick-by-tick data, this offers several advantages: first, it provides reassurance for researchers who might be interested in computing surprises for events other than those currently available in the literature. Second, it provides an easy way to maintain an updated dataset of high-frequency monetary policy surprises.

[2]There are only very few events in which the surprises in our dataset differ from those in Altavilla et al. (2019) by more than one basis point in absolute value. For OIS rates, some differences occurred in the pre-2002 period. As highlighted by Andrade and Ferroni (2021), this can be due to outliers in OIS contracts over the 1999-2002 period due to liquidity issues. For some sovereign yields at some maturities, some small differences are observed in dates of big changes in policy rates, such as April 1999 or October 2008 where the ECB policy rates were cut by 50 bps.

Table 3: Correlation of monetary event surprises calculated using tick-by-tick and minute-by-minute data over the entire monetary policy window for the period 1999-2021

Instrument	Pearson (Linear)	Kendall (Rank)	Spearman (Rank)
EON1M	0.940***	0.762***	0.863***
EON3M	0.992***	0.833***	0.930***
EON6M	0.990***	0.877***	0.956***
EON1Y	0.996***	0.907***	0.967***
EON2Y	0.997***	0.955***	0.989***
EON3Y	0.996***	0.949***	0.989***
EON5Y	0.999***	0.978***	0.994***
EON7Y	1.000***	0.996***	1.000***
EON10Y	1.000***	0.994***	1.000***
DE3M	0.883***	0.739***	0.860***
DE6M	0.975***	0.825***	0.925***
DE1Y	0.994***	0.901***	0.969***
DE2Y	0.998***	0.945***	0.992***
DE3Y	0.999***	0.973***	0.997***
DE5Y	0.998***	0.968***	0.994***
DE7Y	0.987***	0.963***	0.988***
DE10Y	0.998***	0.979***	0.997***
IT2Y	0.995***	0.984***	0.999***
IT5Y	1.000***	0.989***	0.999***
IT10Y	1.000***	0.991***	1.000***
FR2Y	0.993***	0.909***	0.969***
FR5Y	0.998***	0.961***	0.992***
FR10Y	0.998***	0.975***	0.995***
ES2Y	0.996***	0.942***	0.985***
ES5Y	0.999***	0.968***	0.993***
ES10Y	0.999***	0.978***	0.997***

Notes: The table shows correlation coefficients between monetary event surprises computed using the minute-by-minute quotes in combination with the procedure outlined in Section 2.2 and the surprises of Altavilla et al. (2019). $*p < 0.1$;$*p < 0.05$; $***p < 0.01$. Pearson's correlation coefficient is a measure of linear correlation. Kendall's (τ) and Spearman's (ρ) correlation coefficients are, respectively, a parametric and non-parametric measure of *rank* correlation, i.e. the statistical dependence between the rankings of two variables.

3 Twenty Years of Euro Area Monetary Policy. An Event Study Analysis

Our novel dataset of monetary policy surprises allows to look at shifts in the Eonia OIS yield curve and in the pseudo euro area GDP-weighted sovereign yield curve around 278 regular governing council monetary policy meetings occurred between January 1999 and March 2021, as well as eleven additional monetary policy events, as detailed in Table 2. We recall that our definition of monetary policy shock is indeed a shift in the entire term structure of interest rates in a short window of time around central bank monetary policy announcements, using the methodology described in Section 2.2. So, our dataset comprises 289 term structure functional shocks.

In this section, we look at a subset of these monetary policy shocks, in particular we focus on those related to announcements corresponding to an easing or tightening of the monetary stance (i.e., a change in the ECB key interest rates) and to some key announcements of unconventional monetary policy instruments and a few speeches. In addition, Section A in the Appendix discusses the YC responses to other announcements of unconventional tools and their recalibration.

3.1 Conventional Monetary Policy Before the Global Financial Crisis

Figure 1 shows the movements of the two euro area YCs around all tightening and easing announcements occurred over the pre-global financial crisis (GFC) period. For this conventional pre-GFC period, we identify changes in the monetary stance as changes in the Main Refinancing Operation rate (MRO).[3] Data availability of OIS contracts and sovereign yields over this period only allows to consider movements in the short to medium end of the risk-free YC and in the medium and long end of the GDP-weighted YC (see Table 1).

Our sample of conventional monetary policy events begins with the easing cycle started in May 2001, to avoid potential outliers in OIS rates due to liquidity problems in the first years of the contracts (Andrade and Ferroni (2021)). Panels (a) and (b) in Figure 1 depict YC surprises around easing decisions between May 2001 and June 2003. This sample includes seven MRO cuts (three of -25bps and four of -50bps, the latter marked by dotted lines). Panels (c) and (d) show the movements of the YC around the tightening dates for the cycle that started in December 2005 and ended in July 2008. This sample includes nine MRO increases of +25 bps.

[3] Over this period, the choice of the interest rate is anyways neutral as the ECB left the size of the interest rate corridor unchanged and symmetric so that all three key interest rates have been always moved in parallel.

A few results are worth noticing:

i) *Tightening announcements*: All tightening decisions in panels (c) and (d) generated very little surprises to both the risk-free and the GDP-weighted YCs. The 1-month OIS rate moved by only a few basis point around the announcements, and in a few instances in negative territory. Movements at longer maturities in both YC are also small. This result is in line with Istrefi et al. (2022), who show that markets were generally anticipating the change in the direction of policy ahead of the meetings for the same set of tightening decisions. They also show that ECB president speaking events ahead of ECB meetings with monetary policy changes move markets in the same direction as the upcoming decision. Narratives from Bloomberg News coverage of ECB president communication support this result. For instance, a quote with a clear tightening signal only few days before the tightening decision of December 2005 is the following: *"The governing council is ready to take a decision to move interest rates," Trichet said in a speech to a banking conference in Frankfurt today. The ECB will "withdraw some of the accommodation" of its current policy stance.* BBG, November 18, 2005.

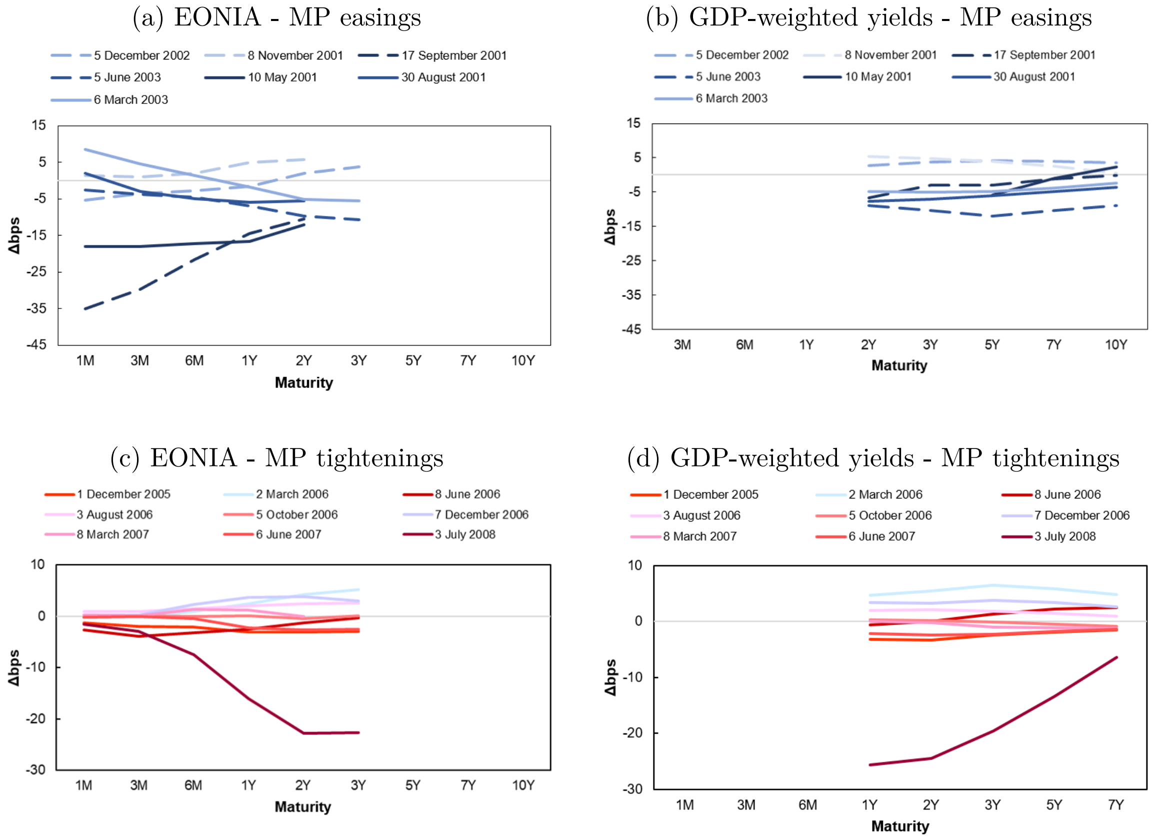
ii) The tightening decision of July 3, 2008 represents an exception. While short-term interest rates did not react much, as the move was widely anticipated, both the OIS and GDP-weighted sovereign YC show a strong negative decrease in medium-term maturities (1 to 3-year rates went down by around 25bps). July 2008 corresponds to the last increase in the ECB key policy rates - motivated by a new record high of inflation in the euro zone - after a one year pause and before the easing move of October 2008, following the default of Lehman Brothers, which we take here as the end of the pre-GFC period. The decrease in medium-term interest rates reflect the fact that markets were pricing further hikes of the policy rate until the press conference of President Trichet who instead refused to confirm that there would be more increases.[4]

iii) *Easing announcements*: Results for the pre-GFC easing decisions in panels (a) and

[4]See ECB Press Conference 3 July 2008.

(b) show sometimes bigger surprises at the short and medium end of the OIS curve than those of tightening announcements. In particular, surprises are large and negative for the one-month OIS rate in two dates: May 2001, corresponding to the start of the easing cycle, and September 2001, when the ECB decided to cut rates more aggressively by 50 bps. As for the tightening sample, the movements of the GDP-weighted YC at long maturities are overall modest in size and smaller than those at short to medium maturities, in line with the conventional nature of these monetary policy decisions.

Figure 1: Changes in yield curves in monetary policy events before 2008



Notes: Dashed lines in Figure 1a an Figure 1b correspond to events where the MRO rate was decreased by 50bps. Solid lines correspond to cuts in the MRO rate by 25bps.
Sources: Reuters and authors' computations.

3.2 Monetary Policy in Crisis Times

We look now at different sets of monetary policy announcements done by the ECB between October 2008 and March 2021. Over this period, the euro area went through three major crises: i) the GFC in 2008-09, ii) the sovereign debt crisis in 2011-12; and iii) the Covid 19 crisis in 2020. Moreover, the context of persistently low inflation and decrease in long-term inflation expectations required a strong monetary policy action and a gradual enlarging of the ECB toolkit.[5]

We consider both conventional monetary policy announcements, which are now defined as movements in the Deposit Rate Facility (DFR)[6], and announcements of some key unconventional measures. For the latter, we focus on four monetary policy tools: the Security Markets Program (SMP) announced for the first time in May 2010, the Outright Monetary Transactions (OMTs) announced in August 2012 (after the famous "whatever it takes" speech of President Draghi in July 2012), the expanded Asset Purchase Programme (APP) announced in January 2015, and the Pandemic Emergency Purchase Programme (PEPP) announced in March 2020.[7] These four measures have been introduced with different aims and in different economic circumstances. In particular, the SMP and OMT can be classified as backstop instruments, i.e. tools that are used only to address potential market failures that can hinder the proper transmission of monetary policy; they are hence not intended to change the monetary policy stance.[8,9] On the other hand, the APP and the

[5]See, among others, Hartmann and Smets (2018) for a comprehensive review of the different instruments introduced by the ECB during its first twenty years.

[6]The DFR became the marginal policy rate since the ECB shifted to a *de facto* 'floor' system with the introduction of the Fixed-rate full allotment (FRFA) tender procedure in October 2008.

[7]In Section A in the Appendix, we also show: i) for each of these four tools, the effect of their successive recalibrations and ii) the effect of the introduction of the negative interest rate policy in June 2014, when the DFR has been moved in negative territory for the first time, and the further four DFR cuts until September 2019.

[8]SMP was designed to address failures in securities markets and restore an appropriate monetary policy transmission mechanism. The ECB purchased Greek, Irish and Portuguese government bonds, and from August 2011 extended purchases to Italian and Spanish government bonds. The purchases were sterilized to avoid an increase in central bank liquidity through weekly time deposit operations. For a detailed analysis of the effects of SMP purchases on yields see Eser and Schwaab (2016) and Ghysels et al. (2017).

[9]OMTs have been introduced to safeguard an appropriate monetary policy transmission and the singleness of monetary policy. It consists of purchases in the secondary sovereign bond markets, conditional on the beneficiary country to accept strict and effective conditionality attached to an appropriate European Financial Stability Facility/European Stability Mechanism (EFSF/ESM) programme. To date, no

PEPP are both balance sheet policies aimed at providing monetary policy accommodation at the ELB. However, while the APP had a strict stance objective[10], the PEPP have been introduced with a double objective of stance and transmission.[11]

Note that in this section, we focus on unconventional measures involving the purchase of government debt and decisions on key interest rates (negative interest rate announcements) and do not consider announcements of forward guidance or long-term refinancing operations (LTROs and TLTROs), although they too are unconventional instruments introduced by the ECB in the last decade.

Panels (a) and (b) of Figure 2 show the YC surprises around all conventional easing decisions taken over the period 2008 to 2012, till the DFR reached the level of zero.[12] The first easing cycle, under President Trichet, began with the coordinated move of the Bank of Canada, the Bank of England, the ECB, the Federal Reserve System, the Sveriges Riksbank and the Swiss National Bank on 8 October 2008 and ended in April 2009. The second easing cycle, under President Draghi, started in November 2011 and ended in July 2012 when the DFR reached zero.[13] We plot standard DFR cuts of 25bps with solid lines and bigger cuts with dotted lines.[14]

Panels (c) and (d) show the YC movements following the announcements of the four unconventional measures described above (SMP, OMTs, APP and PEPP). For each of these measures, we plot the YC movements around the date of the first announcement only[15], while Section A of the Appendix shows the YC surprises for each recalibration of these measures. Notice that, for the OMTs, we plot here the monetary policy shock corresponding to President Draghi "Whatever it takes" speech on July 26, 2012, instead

purchase has been made through the OMT programme.

[10]Secondary market purchases of public securities under the APP have been conducted proportionally to the capital keys of members countries.

[11]Secondary market purchases under PEPP were conducted in a flexible manner on the basis of market conditions. The flexibility of purchases over time, across asset classes and among jurisdictions was intended to support the smooth transmission of monetary policy.

[12]We do not show in here the YC surprises around the two tightening decisions of April and July 2011.

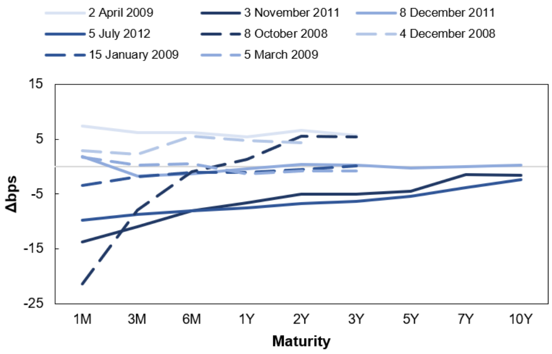
[13]Other five moves decreased the DFR from 0 to -50bps between June 2014 and September 2019.

[14]The ECB cut the DFR by 50bps in October 2008 and March 2009, by 75bps in December 2008 and by 100bps in January 2009.

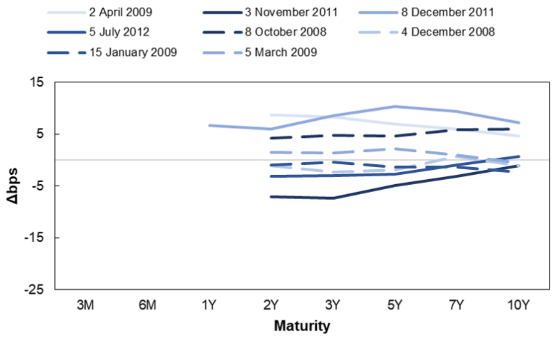
[15]Notice that, for a given maturity, when the surprise of one of the four euro area countries' yields is not available, the corresponding maturity of the average GDP-weighted curve is set to NaN in our database and not shown in the charts.

Figure 2: Changes in yield curves in monetary policy events during crisis times

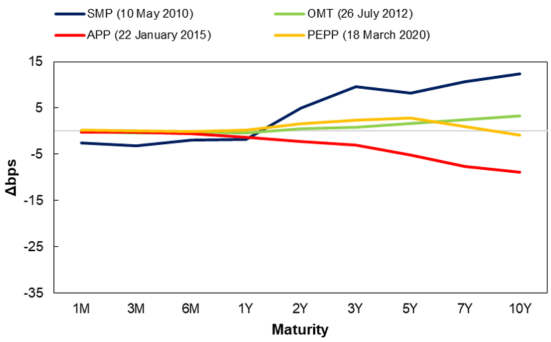
(a) EONIA - MP easings



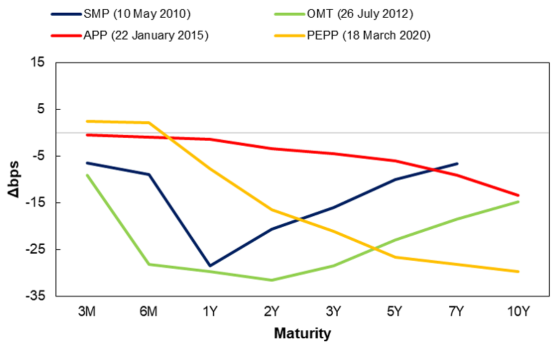
(b) GDP-weighted yields - MP easings



(c) EONIA - unconventional measures



(d) GDP-weighted yields - unconventional measures



Notes: Dashed lines in Figure 2a an Figure 2b correspond to events where the DFR rate was decreased by 50bps or more. Solid lines correspond to cuts in the DFR rate by 25bps.
Sources: Reuters and authors' computations.

of the proper OMT announcement at the following governing council meeting of August 2012. It is indeed widely recognized that the speech has been the major event dampening redenomination risk in the euro area, although the details of the monetary instrument have been disclosed only later.

A few results are worth noticing:

i) *Conventional announcements*: as for the pre-GFC sample, surprises in the risk-free YC at short maturities tend to be sizable at the beginning of each easing cycle, namely in October 2008 and November 2011. Along the cycle, markets largely incorporated monetary policy movements in advance, also thanks to speeches and other forms of communication by central bank officials that have been found to have a large and significant effect on yields, especially before Governing Council meetings implementing a change in the monetary policy stance (see Istrefi et al. (2022)). An additional event that has exerted a significant decrease in the short end of the risk-free YC is July 2012 when the DFR reached the zero lower bound, which at that time was still considered to be the effective lower bound of euro area policy rates.

ii) Overall, as expected, those conventional events did not substantially move the GDP-weighted YC at medium and long maturities. One exception is the first DFR cut of President Draghi in November 2011, which intervened just few months after the short tightening cycle of mid-2011 and in a context of increasing tensions in sovereign debt markets of peripheral euro area countries. This easing decision was able to temporarily reduce the short and medium sovereign rates of Italy and Spain but was neutral on longer maturities. The spreads between Spanish and Italian sovereign yields and their German counterpart continued indeed to rise until mid-2012 and the introduction of the OMTs.

iii) *Unconventional announcements*: All four unconventional announcements had a strong negative impact on the GDP-weighted YC at medium and/or long maturities. Instead, they only had small effects on the risk-free YC and sometimes of the opposite intended sign. The APP effect on the OIS YC is however different from that of the other measures. As mentioned before, the APP has been announced in January 2015[16] to counter serious risks of deflation in the euro area and with a clear stance objective. This is consistent with the decrease in the medium and long end of the risk-free YC, hence with an easing of the stance. In other words, while the SMP and the OMT have operated mainly through their effects on the credit risk of peripheral countries, the response of the OIS YC seems to suggest that the APP has also operated as a substitute of conventional monetary policy at the ELB.[17]

iv) The response of the average GDP-weighted sovereign yield curve hides by construc-

[16]Small scale private sector purchases programmes were already introduced in 2014 but the APP in its extended version, including public sector purchases, has been announced in January 2015 and implemented from March 2015.

[17]This is in line with some of the existing literature, e.g. Gambacorta et al. (2014).

tion the different responses of the yields of the four countries considered. Indeed, while the APP announcement has decreased medium and long-term yields of all four countries in a very similar way (between 13 and 15 bps for 10-year yields) - confirming again the stance nature of this measure - the other unconventional measures had in general very different effects on core vs. peripheral countries through their effects on risk premia.[18] The SMP announcement of May 2010 substantially decreased medium-term yields (2-year), by about -80 and -95 bps, and 10-year yields (by about -30 and -50 bps, respectively) of Italy and Spain. Instead, it had only a small and positive effect on French yields and a larger positive effect on German yields (the 10-year Bund increased by about 15 bps). The "Whatever it takes" speech (proxy here for the OMTs announcement) had very similar effects, with strong negative effect on the 2-year rates of Italy and Spain (about -90 and -70 bps) and 10-year rates (about -40 and -45 bps, respectively), while being overall neutral on French and German yields. Finally the PEPP announcement of March 2020 had a strong negative effect on Italian yields (about -100 bps on 3-year rates and -70 bps on 10-year rates), a negative impact on Spanish yields (about -30 bps on 10-year yields) and only a marginally negative effect on French long-term yields (about -10 bps on 10-year rates). The German yield curve moved instead upward marginally at all maturities. The fact that German yields generally increased following announcements of instruments aimed at improving the transmission of monetary policy through reduction of fragmentation and/or redenomination risks is well established by the literature. It relates to the safe-asset nature of Bunds and the existence of a scarcity and a liquidity premium in the Bund market, which have increased over time following the implementation of asset purchases programmes by the ECB (e.g., see Rogers et al. (2014) and Bundesbank (2018)).

[18] See Pagliari (2021) for an analysis of the differential effects of non-standard measures in core and peripheral countries.

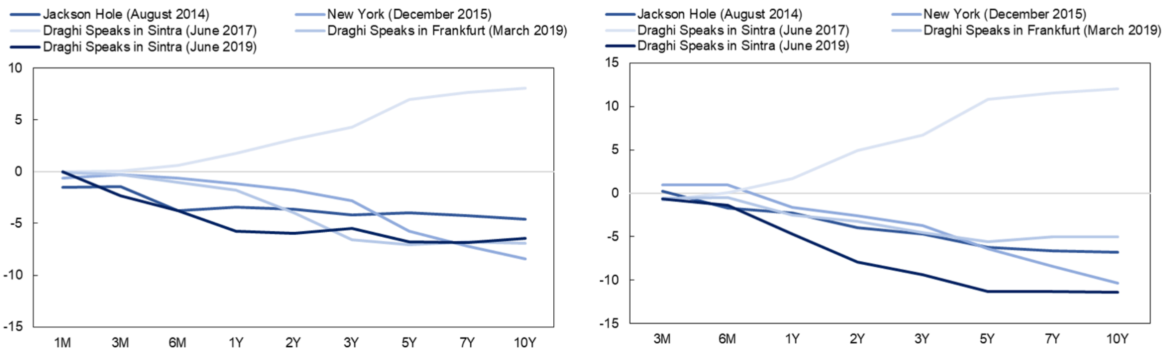
3.3 The Effect of Speeches

We now look at the YC changes in the day of some key speeches given by President Draghi in the period 2014-19. In the choice of the speeches, we follows Rostagno et al. (2021), who identify five speeches as having had a strong and significant effect on euro area yields in this period.[19]

YC changes depicted in Figure 3 are aligned with their result. Indeed, all five events have impacted both the OIS and the GDP-weighted yield curves in a significant way. The effect is particularly large at medium and long maturities, suggesting that those speeches operated similarly to unconventional monetary policy announcements at the ELB. While four of them have exerted a substantial easing on the euro area YCs, one speech - delivered in Sintra in June 2017 - stands apart for its strong positive impact on both curves. Similarly to Rostagno et al. (2021), we see this overreaction as a sign of a *Delphic* interpretation of the speech by markets, which took Draghi's description of the improved economic outlook as a potential signal of an upcoming monetary policy normalization, in opposition to the *Odyssean* policy signal associated with the other selected speeches.

Figure 3: Changes in yield curves after key ECB's President speeches

(a) EONIA (b) GDP-weighted yields



Sources: Reuters and authors' computations.

Overall, this evidence is in line with a growing literature that expands the set of monetary policy events to be studied to assess the overall effect of monetary policy (for the ECB, see Born et al. (2014), Gertler and Horvath (2018), Tillmann and Walter (2019),

[19]While they look at the impact over a two-day window, our definition of surprise for these additional events is one-day surprises, as described in Section 2.2.

Leombroni et al. (2021) and Istrefi et al. (2022)). While it is critical to understand the effect of announcements on the day of monetary policy meetings, looking at other forms of communication by central banks helps shedding light on financial markets' expectations of central banks' action.

4 Macroeconomic Impact: Empirical Results

4.1 The Model

In this section, we estimate the effects of selected monetary policy shocks on two euro area macroeconomic aggregates, namely inflation and industrial production. As discussed previously, the monetary policy shocks are the exogenous shifts in the term structure of OIS yields around monetary policy events. The monetary policy shock is thus a function: namely, the change in interest rates at various maturities, viewed as a function of the maturities themselves. We therefore follow the approach in Inoue and Rossi (2021) to estimate the effects of the multi-dimensional shock.

Differently from Inoue and Rossi (2021), however, we identify and estimate the response of macroeconomic aggregates to the functional shock using an approach based on a Functional Vector Autoregressive model with exogenous variables (Functional VARX). The Functional VARX approach that we introduce in this paper has several advantages. First, since we only have a handful of available maturities, it conveniently captures the whole shape of the shock without any approximation. Second, it provides smooth impulse responses by construction, while the local projection approach might require an additional smoothing step.

The Functional VARX model has the following specification:

$$Y_t = \mu + A(L)\,Y_t + BX_t + \Gamma t + U_t, \tag{1}$$

where Y_t is an $(n \times 1)$ vector of endogenous macroeconomic variables, X_t is the $(m \times 1)$ vector of exogenous variables, $A(L) = A_1 L + ... + A_p L^p$, A_j and B are respectively $(n \times n)$ and $(n \times m)$ matrices of coefficients, μ is a constant, t is a deterministic time trend and U_t

are reduced-form residuals. The variable X_t contains the (multivariate) functional shock. The number of lags is determined by the BIC.

The endogenous variables (Y_t) include euro area HICP inflation (year-on-year), industrial production (year-on-year growth rate) and the two-year nominal interest rate (the 2-year OIS rate), while the exogenous variables include the high-frequency shocks, namely the change in the OIS term structure in a short window of time around the monetary policy event (ΔTS_t^M), as detailed in Section 2.2, using maturities of 1, 3 and 6 months as well as 1 to 2 years.[20] Industrial production is total industrial production excluding the construction sector, seasonally adjusted. The data source for these variables is Eurostat and they were downloaded from the ECB's SDW. We estimate the Functional VARX model using monthly data from August 2003 until March 2021.

However, note that a shock at the beginning of the month may have very different effects than a shock at the end of the month, since the former would have an entire month to affect the macroeconomic variables while the latter would have only one day. Hence, the results we discuss in the next two sections are based on monthly weighted shocks, obtained as follows.[21] Each shock, namely each change in the yield curve around a monetary policy event, denoted here by ΔTS^{t_k} is given a weight, w, that depends on the day of the month on which the related monetary policy event (t_k) takes place. Notably, $w_{t_k} = [D - (d+1)]/D$, with d being equal to the day of the monetary event t_k in month t and D is the total number of days in month t. The remaining fraction of the shock, $(1 - w_{t_k})$, is attributed to the following month. Therefore, $\Delta TS_t^M = \sum_k w_{t_k} \Delta TS^{t_k} + \sum_k (1 - w_{(t-1)_k}) \Delta TS^{(t-1)_k}$ $\forall t = 1, \ldots, T$, where $\sum_k (1 - w_{(t-1)_k}) \Delta TS^{(t-1)_k}$ is the portion of shock carried over from the preceding month. If there is more than one monetary policy event in month t, ΔTS_t^M is the sum of the weighted changes on days of monetary policy events.

An important caveat is that our approach focuses on high frequency surprises identified in a small window of time around monetary policy events. The reason why we focus on a short window of time around the monetary policy event is to rule out other shocks,

[20]The choice of maturities is dictated by data availability and the necessity of using a long enough sample size for inference.

[21]The procedure is inspired by Gertler and Karadi (2015).

unrelated to monetary policy, that could potentially contaminate our surprises. Therefore, our empirical results should be understood as estimates of the magnitude of the effects of the surprises during the monetary policy event. It is however possible that monetary policy actions taken in that period might have been bigger (due to an anticipated component that is excluded by construction from the surprises) and, hence, had larger effects; however, the exogenous shocks associated with such anticipated actions are not easily identifiable, and failing to identify the exogenous component would imply empirical estimates that are subject to the Lucas critique, and therefore inconsistent. Nevertheless, one could infer the magnitude of the effects of larger surprises on the macroeconomy based on our estimates. Alternative approaches to identification have been attempted in the literature (e.g. sign identification); although each approach has its pros and cons, ours does not have the drawback of requiring to decide ex-ante the sign of the effects, which in the case of unconventional monetary policy would be particularly debatable. Our approach does not impose indeed any assumption on the sign of the response of macroeconomic aggregates.

4.2 Counterfactual Analysis: Does the Shape of Monetary Policy Shocks Matter?

In this section, we aim to answer the following question. Suppose that the central bank has a choice of instruments to stimulate the economy, but each of them has a different effects on the yield curve: which policy would give the desired effect? For instance, the central bank could implement policies to lower the short-end but not the long-end of the yield curve; or it could implement policies to lower the long-end more than the short-end. We therefore conduct an exercise that simulates different scenarios of how the central bank changes the yield curve; then, using the estimated parameters of the Functional VARX model, we investigate how the different *simulated* policies would affect the macroeconomic variables of interest.

To see if and how the shape of the monetary policy shock matters in determining how the macroeconomic variables react to the shock itself, we simulate different types of functional shocks. In particular, we focus on how the responses depend on the sign and the shape of the functional shocks.[22] In standard impulse responses to monetary policy shocks, the shock is a scalar and therefore scalable to easily interpret counterfactuals - e.g., the impact of a 100 bps shock on the policy rate, for example. In our Functional VARX, the shock is multivariate, which raises the question of how to scale and compare counterfactual shocks. Our proposal is to measure the effect of a functional monetary shocks ($\{s_m\}_{m=1M}^{2Y} = [s_{1M}, s_{3M}, s_{6M}, s_{1Y}, s_{2Y}]'$, where m denotes the maturity, ranging from one month, 1M, to two years, 2Y) by the cumulative nominal interest rate flows to an investor (respectively, borrower) who buys (borrows) a uniformly-weighted and continuous portfolio of *new* securities up to two years. The investor will gain one month of s_{1M}, three months of s_{3M} and so on. More formally, the contribution $c_{s,m}$ of each shock is thus: $c_{s,m} = s_m m w$, where s_m is the shock in basis points on an annualised basis at maturity m measured in years and w is the weight of the instrument in the portfolio (where w is a constant). The cumulative sum of the contributions in continuous form, normalising out w, is

$$\Sigma = \int_0^2 s_m m \partial m.$$

To construct normalized shocks, we consider two cases:

(i) *Uniform "level" shocks.* In this case, $s_m = s \; \forall m$, and the cumulative sum over two years is

$$\begin{aligned} \Sigma_{level} &= s \int_0^2 m \partial m \\ &= 2s. \end{aligned}$$

(ii) *General yield curve shocks.* In the case of a general yield curve of the form $s_m = sf(\theta, m)$, the cumulative sum over two years is

$$\Sigma_L = s \int_0^2 f(\theta, m) \, m \partial m.$$

[22] Notably, given a vector of simulated changes in the yield curve, $\hat{\boldsymbol{s}} = [\hat{s}_{1M} \; \hat{s}_{3M} \; \hat{s}_{6M} \; \hat{s}_{1Y} \; \hat{s}_{2Y}]$, the estimated impact on inflation and output growth at horizon h is given by $\hat{A}^h \hat{B} \hat{\boldsymbol{s}}$, where $\hat{A}$ and $\hat{B}$ are the OLS estimates of the matrices A and B from Equation (1).

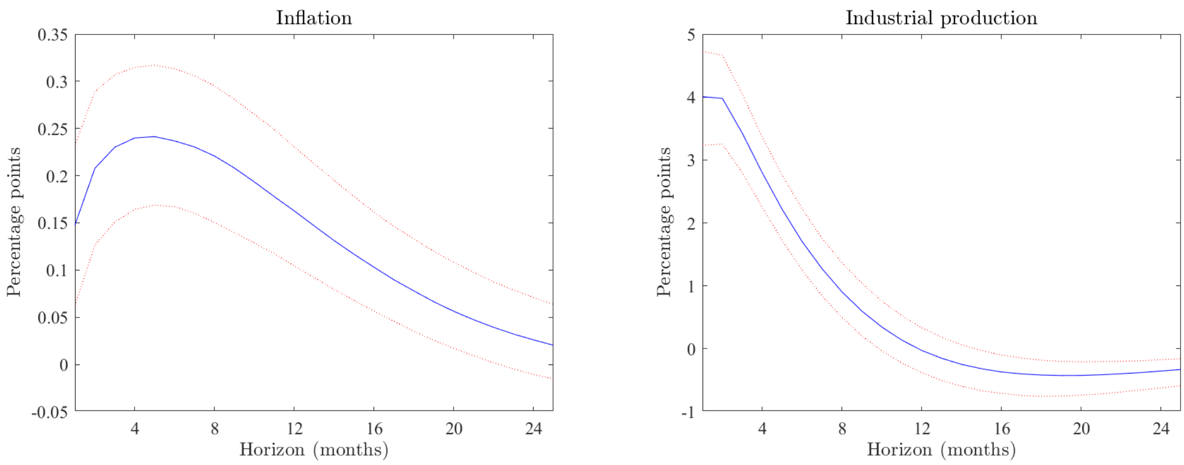
For example, the calibrated shocks we will consider in what follows in Figures 5 and 6 are $f(\theta, m) = \alpha + \beta m$ such that

$$\int_0^2 (\alpha + \beta m) m \partial m = 2,$$

with s equal to 10 basis points for the expansionary shocks and -10 basis points for the contractionary shocks for different values of α and β.[23] In this way, we are able to study shocks that are comparable in terms of magnitude but entail different shapes of the yield curve. Note that, in this framework, a uniform shock of -10 bps therefore amounts to a -20 bps cumulative shock for 2 years. Note that this is likely to be a much more expansionary shock than a standard -20 bps shock to the short-term policy rate only because the latter shock dies out more quickly over time.

Figure 4: Simulated effects of a uniform level shock of -10 bps

(a) Inflation (b) Industrial production



Notes: Dotted lines represent 68 percent confidence bands based on Monte Carlo simulations.
Source: Authors' calculations.

Figure 4 shows the impact of a uniform level shock of -10 bps over inflation and industrial production; that is, the shock we consider is:

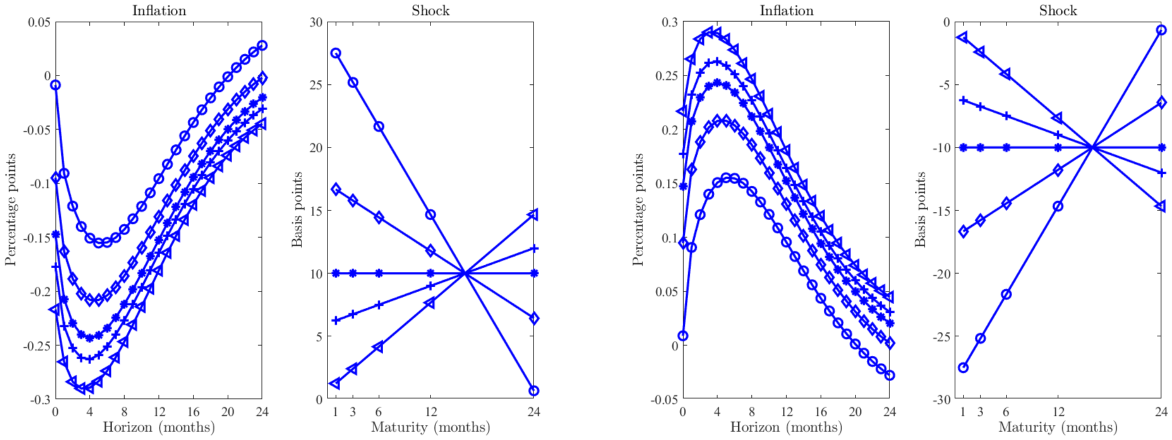
$$\{s_m\}_{m=1M}^{2Y} = [-10bps, -10bps, -10bps, -10bps, -10bps]'.$$

Note that this shock is expansionary, as it unambiguously decreases yields at all maturities.

[23] The constraint above implies that $\alpha = 1 - \frac{4}{3}\beta$.

Figure 5: Calibration exercise - Inflation

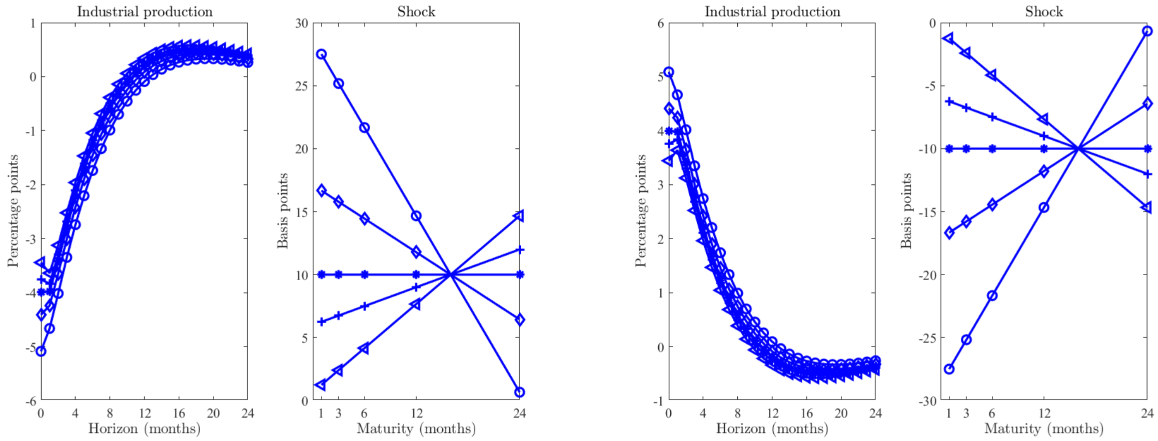
(a) Contractionary shocks (b) Expansionary shocks



Notes: Each plot in Figures (a) and (b) shows the shock (right panels) and the corresponding median response of the macroeconomic variable (left panels).
Source: Authors' calculations.

Figure 6: Calibration exercise - Industrial production growth

(a) Contractionary shocks (b) Expansionary shocks



Notes: Each plot in Figures (a) and (b) shows the shock (right panels) and the corresponding median response of the macroeconomic variable (left panels).
Source: Authors' calculations.

Figure 5 depicts instead the inflation effect of a series of contractionary and expansionary functional shocks with non-uniform shapes, based on our estimated model. Notably, for each set of shocks, the panel on the right shows the shocks, each identified with a separate marker; the panel on left plots the estimated response of inflation associated to each shock using the corresponding marker. The remaining figures in this section have a similar structure. In particular, Figure 6 shows the effects of contractionary and expansionary non-uniform shocks on industrial production growth. Figure 7 and Figure 8 focus instead on shocks with more complex dynamics, contractionary at some maturities and expansionary at others.

We can draw several interesting observations. First, a uniform positive shock generates a decrease of inflation at impact, with a peak of about -0.25 pp after four months, and dies out after about two years. This is a very rapid response relative to other estimates of monetary shocks in the euro area (for example Angelini et al. (2019)). Second, generally speaking, the shocks entailing the biggest decreases in inflation are those where changes in the yield curve are upward sloping, i.e. those leading to more pronounced increases at the longer-end of the yield curve ('△' and '+' lines). Conversely, downward sloping shifts, i.e. moving short-term maturities more than long-term ones ('o' and '⋄' lines), have less effect than the uniform shock ('*' line). The effects of expansionary shocks have the same effects with opposite signs (Figure 5b). This suggests that events that had a powerful effect on longer term yields, like speeches (see Figure 3), were particularly effective at reversing the downward drift in inflation. This also highlights the importance of including those events in the set of monetary policy events.

The effects on industrial production are much very similar across the shocks. Industrial production falls sharply on impact and fades away within a year (Figure 6). Somewhat surprisingly, downward-sloping contractionary shocks - those that load most of the effect at short maturities - have the strongest effect on industrial production (although the difference is minor).

Overall, the study of fully contractionary/expansionary shocks shows that our results do not suffer from the so-called "price puzzle", i.e. the presence of counter-intuitive effects of monetary policy shocks on inflation which VAR frameworks often produce.[24]

To complete the analysis, we also consider the effect of simulated "mixed" shocks - shocks constructed to have the *same cumulative* change in the term structure but *different signs* at the short-end versus the longer-end of the curve. In particular, Figure 7 shows

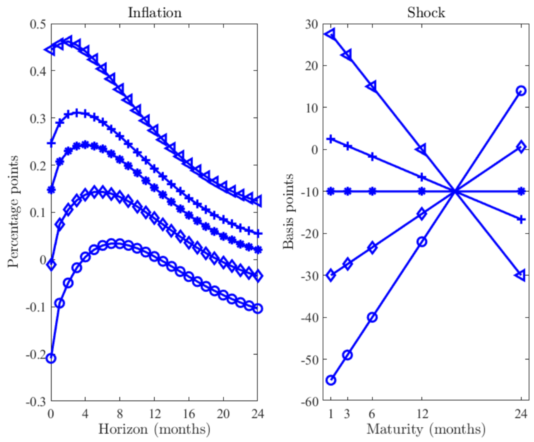
[24] As a robustness check, we estimate a VARX by including only the short-term (three-month) OIS high-frequency shocks as the exogenous variable, as typically done by the empirical VAR literature. Also under this specification, our results do not suffer from the price puzzle.

the effect of functional shocks that are cumulatively expansionary, i.e. all equivalent in size to the uniform shock of -10 bps shown before, which is also depicted for comparison. In the same vein, Figure 8 shows the effect of cumulatively contractionary functional shocks. Shocks with these mixed profiles do occur occasionally, as shown in the event study section (see Figure 1 and Figure 2).

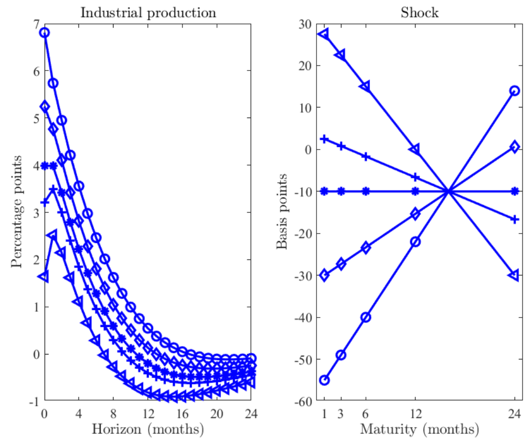
Figure 7 and Figure 8 show that, consistently with what observed for non-mixed shocks, the behaviour of inflation is influenced mostly by the changes in the longer-term of the yield curve, between the impact and the eight-month-ahead horizon. Indeed, depending on the profile, the initial effect of a cumulatively expansionary shock can cause inflation to decline. This is the case for deep cuts in short-term rates offset by increases at the longer end. This analysis highlights that it is not enough to look only at the reaction of the short end of the yield curve to identify the effect of monetary policy shocks. By contrast, cumulatively expansionary shocks increase industrial production on impact, whatever the configuration of the profile of the shocks.

Figure 7: Calibration exercise - Mixed shocks (cumulatively expansionary)

(a) Inflation



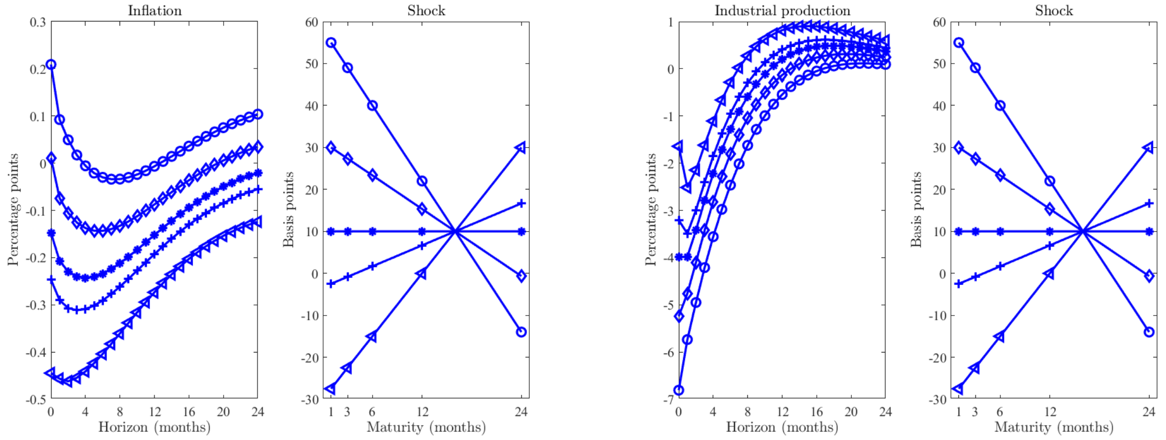
(b) Industrial Production growth



Notes: Each plot in Figures (a) and (b) shows the shock (right panels) and the corresponding median response of the macroeconomic variable (left panels).
Source: Authors' calculations.

Figure 8: Calibration exercise - Mixed shocks (cumulatively contractionary)

(a) Inflation (b) Industrial Production growth



Notes: Each plot in Figures (a) and (b) shows the shock (right panels) and the corresponding median response of the macroeconomic variable (left panels).
Source: Authors' calculations.

4.3 Macroeconomic effects of selected monetary policy events

As a second exercise, we show the response of the macroeconomic variables to the surprises *observed* around some selected monetary policy events. In particular, we analyse a few events, among those described in Section 3, which have lead to sizeable changes in the OIS yield curve in a short window of time around the announcements.[25] We report median and 68% confidence bands for the impulse responses, based on Monte Carlo simulations.

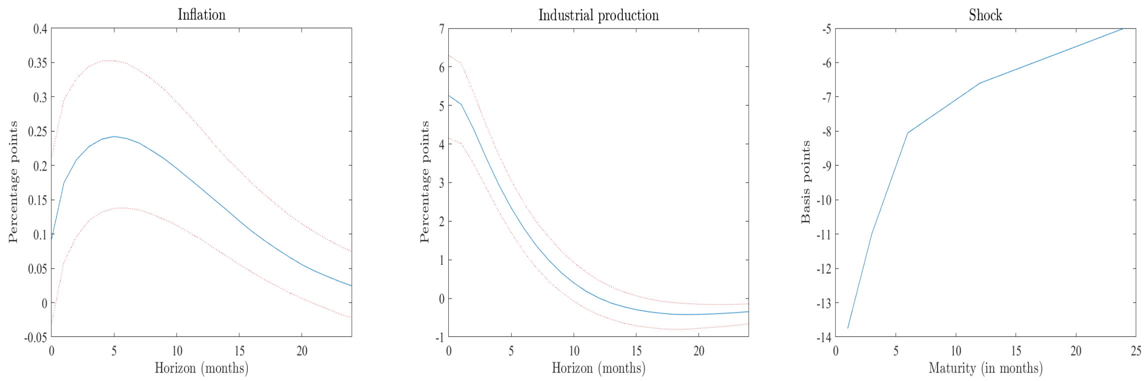
We start our analysis focusing on a few conventional *easing* episodes. Due to the sample, starting in August 2003, we look only at easing decisions in the post-crisis period. As discussed in Section 3.2 and shown in Figure 2, the ECB decided to ease monetary policy on November 3, 2011, in the wake of the euro area sovereign debt crisis, by decreasing all key rates by 25 basis points. The same decision was taken on July 5, 2012. As shown in Figures 9 and 10, those events generated a strong decrease in OIS yield curve at all maturities, with a sizable pass-through at the very short end, with the one-month OIS rate dropping by 14 and 10 bps, respectively, over the two monetary events. In both cases macroeconomic aggregates are positively impacted, with industrial production growth

[25] Note that, since the model includes industrial production in growth rates, the effects on industrial production are in percentage points, e.g. moving from 1 percent to 2 percent is an increase of one percentage point.

increasing by around 5 and 3.5 pps on impact, decaying monotonically over time and becoming insignificant after approximately one year (Figures 9b and 10b). The effect on inflation is instead modest, hovering around 0.25 and 0.2 pp at its peak, although more persistent over the two-year horizon (Figures 9a and 10a). These functional shocks are very similar in nature, as they entail a downward shift of the entire yield curve. The signs of the macroeconomic effects are as expected and significant.

Figure 9: Monetary Policy Meeting on November 3, 2011

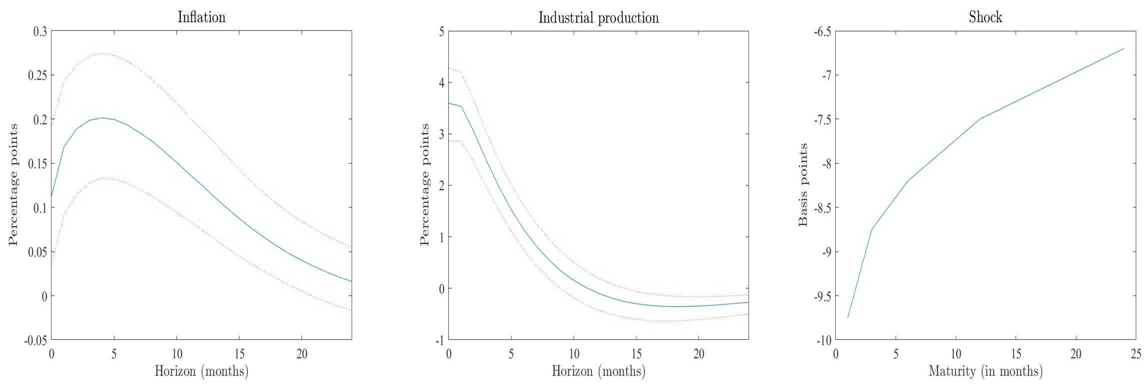
(a) Inflation (b) Industrial Production (c) Shock



Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

Figure 10: Monetary Policy Meeting on July 5, 2012

(a) Inflation (b) Industrial Production (c) Shock

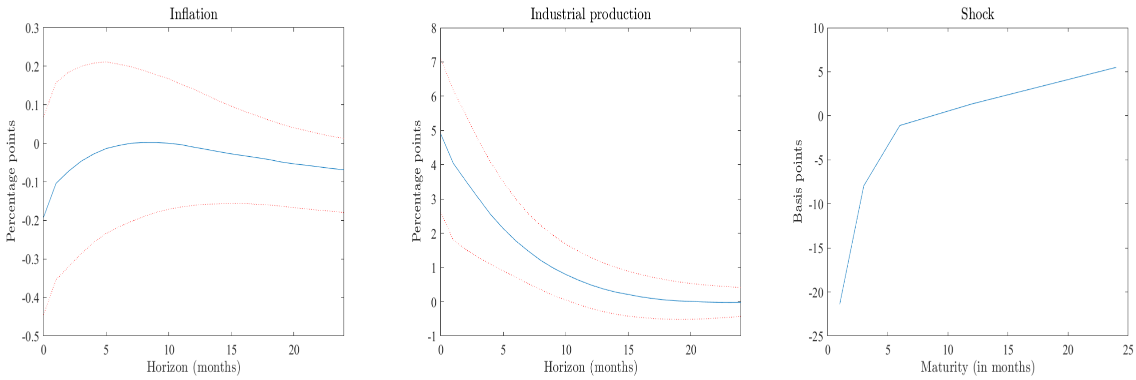


Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

However, there are other announcements with a less clear-cut impact on the yield curve. The combination of different movements across maturities might result in an overall effect on inflation and/or industrial production that is not significant or does not have the expected sign. An example is the easing announcement on October 8, 2008. This episode, which took place in the early part of the global financial crisis, when most of the ECB unconventional monetary measures were still not in place, can be still characterized as "conventional", i.e., the OIS yield curve responded more to the announcement on the short end (maturities up to 6 months), while the impact on the medium-end was muted, or even on the opposite sign for longer maturities. Therefore, these events led to a steepening of the OIS yield curve. Looking at the IRFs of industrial production growth and inflation (Figure 11), it can be noticed that the former significantly increases by 5 pps at impact while inflation does not significantly react to the shock. These macroeconomic responses are in line with what shown in Section 4.2 for mixed shocks.

Figure 11: Monetary Policy Meeting on October 8, 2008

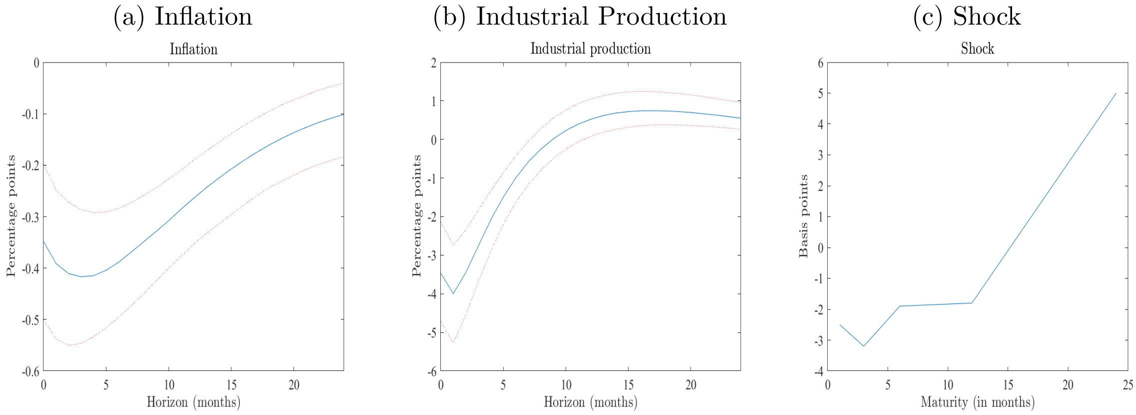
(a) Inflation (b) Industrial Production (c) Shock



Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

We consider now the effects on the economy from the surprises generated by some selected unconventional monetary policy decisions.The first two episodes we consider are related to the announcements of the ECB Securities Markets Programme (SMP), which occurred following two unscheduled monetary policy meetings. The first announcement of SMP was in May 10, 2010. The goal of the SMP was to contribute restoring the monetary policy transmission mechanism by addressing the malfunctioning of certain government bond markets, resulting in outright secondary market purchases. As discussed in Section 3.2, this monetary policy decision, while having a strong negative impact on the GDP-weighted yield curve at one and two-year maturities, decreased only marginally the short end of the OIS curve but resulted in a positive increase in OIS rates from the two-year maturity onward, as depicted in Figure 12. The "twist" in the term structure is linked to a decrease in inflation of -0.4 pp and in industrial production growth (about -4 pps).

Figure 12: Monetary Policy Meeting on May 10, 2010



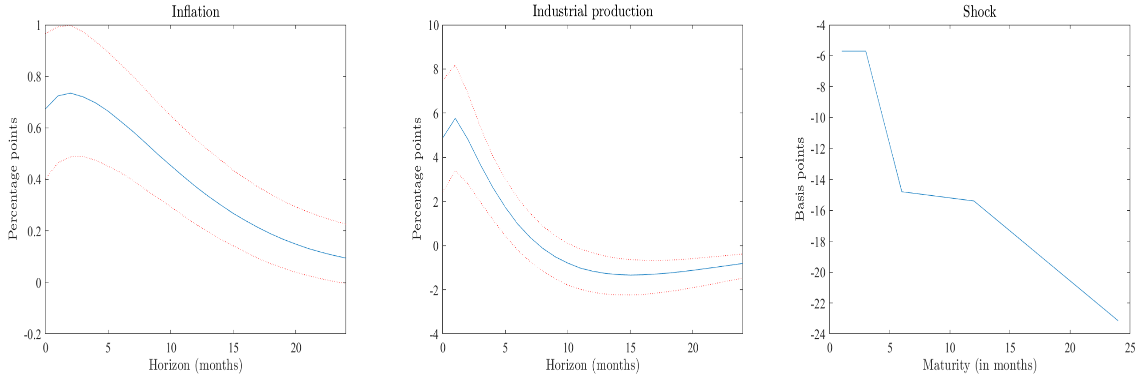
Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

On Sunday, August 7, 2011, the ECB announced through a statement by the ECB President that it would again begin actively implementing the Securities Markets Programme, extending it to purchases of Italian and Spanish government bonds. OIS interest rates substantially declined at the short end and, especially, at the medium and long end of the term structure. As Figure 13 shows, the response of industrial production growth to such surprise is estimated to be positive with an increase of about 6 pps at its peak (soon after the announcement) while inflation increases by around 0.7 pp over the same horizon. The effect on inflation appears to be quite persistent.

We then consider one event related to quantitative easing policies: the announcement of the tapering of the APP in June 2018. On June 14 2018, the ECB announced its intention to phase out its bond-buying program by the end of the year. However, the ECB recognized that the euro area might still need “significant monetary stimulus to support the further build-up of domestic price pressures and headline inflation developments over the medium term. This support will continue to be provided by the net asset purchases

Figure 13: Monetary Policy Meeting on August 7, 2011

(a) Inflation (b) Industrial Production (c) Shock

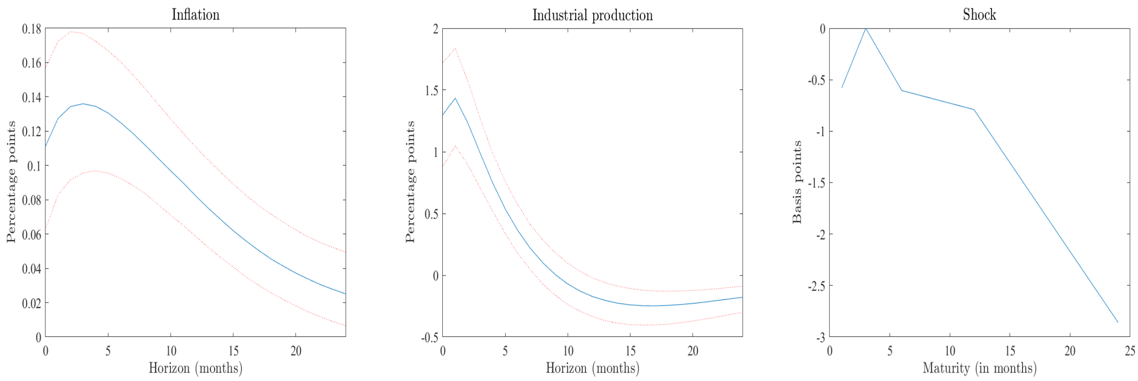


Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

until the end of the year, by the sizeable stock of acquired assets and the associated re-investments, and by our enhanced forward guidance on the key ECB interest rates".[26] Thus, while the end date of QE was settled, the ECB left the door open for additional easing, if needed. This monetary policy decision led to a decrease in the term structure, as depicted in Figure 14, resulting in a subsequent small increase in both inflation and industrial production.

Figure 14: Monetary Policy Meeting on June 14, 2018

(a) Inflation (b) Industrial Production (c) Shock



Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

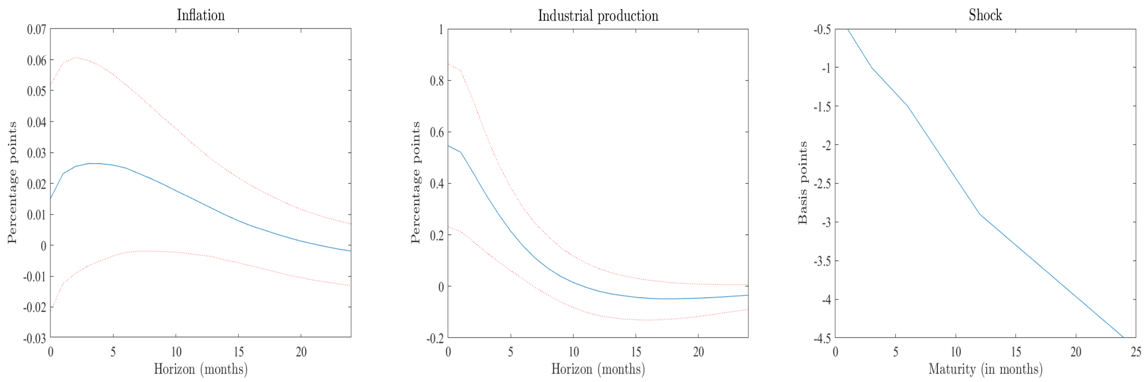
We conclude this section by looking at what it is considered the first important ECB

[26]See ECB Press Conference 14 June 2018.

forward guidance announcement that took place on July 4 2013. During the press conference, the ECB President stated that "[...]our monetary policy stance will remain accommodative for as long as necessary. The Governing Council expects the key ECB interest rates to remain at present or lower levels for an extended period of time."[27] The event pushed OIS rates down more at the medium-term maturities, with a maximum decrease of 4.5 bps for the two-year rate. According to our estimates, this shift in the yield curve had very limited impact on inflation and output growth (Figure 15).

Figure 15: Monetary Policy Meeting on July 4, 2013

(a) Inflation (b) Industrial Production (c) Shock



Notes: Each plot in the picture shows the shock (panel (c)) and the corresponding response of the macroeconomic variable (panels (a) and (b)) with 68 percent confidence bands.
Source: Authors' calculations.

5 Conclusion

This paper takes a new perspective on the analysis of euro area monetary policy. We make three main contributions to the existing literature.

A first contribution is to describe euro area monetary policy surprises by the whole change in the yield curve around euro area monetary policy events. Those include all monetary policy decisions taken in regular ECB monetary policy meetings, as well as some announcements outside regular meetings and a few speeches by the ECB President.

A second contribution is to build a novel database of euro area surprises based on minute-by-minute data. We show that minute-by-minute surprises are very similar to

[27] See ECB Press Conference 4 July 2013.

the tick-by-tick data considered in the literature; however, the former are much more convenient to work with and can be easily extended to include other events or financial instruments.

A third contribution is to develop and estimate a Functional VARX methodological approach to quantify the effects of such shocks on euro area macroeconomic aggregates. A counterfactual analysis, based on the estimated parameters of the model and using simulated functional shocks, shows that the shape of the monetary policy shock does matter for the effect on the macroeconomy. Notably, the shape matters even if the cumulated effect on the yield curve is similar. Movements in the longer end of the curve seem to dominate those in the short end for what concerns the effects on inflation of shocks of comparable size. When looking at mixed shocks, i.e. shocks of comparable size but entailing a different sign on the short vs. the longer end of the OIS curve, results point to different effects depending on the shape of the shock.

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Appendices

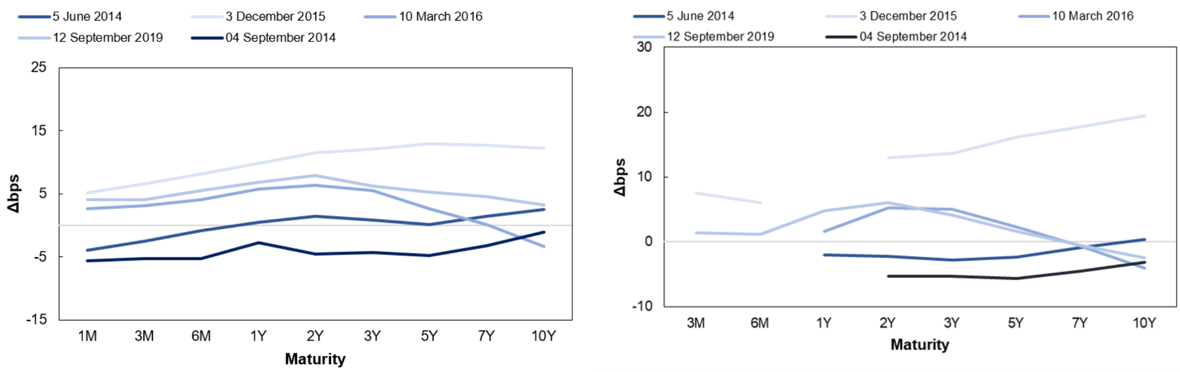
A Additional Monetary Events

A.1 Announcements of Negative Interest Rates

Figure 16 shows the OIS and GDP-weighted YC surprises following the announcements of cuts in the DFR below zero. The ECB initiated its negative interest rate policy in June 2014, moving the DFR to -0.10 percent. It then decreased the policy rate in other four meetings from September 2014 to September 2019 till reaching -0.50 percent.

Figure 16: Changes in yield curves in monetary policy events at the ZLB

(a) EONIA (b) GDP-weighted yields



Sources: Reuters and authors' computations.

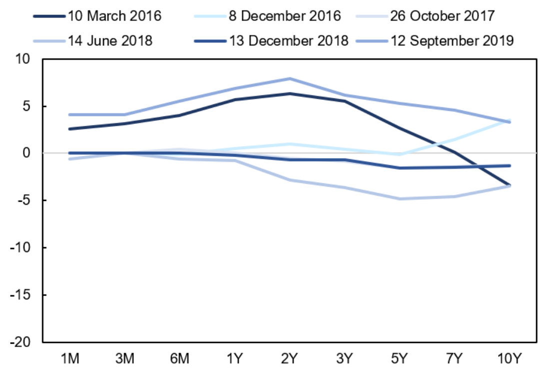
A.2 Announcements of Different Re-calibrations of Unconventional Tools

Figure 17 shows the surprises in the OIS and GDP-weighted yield curves following the re-calibrations announcements of the four unconventional measures described in Section 3.2. Panels (a) and (b) show the movements following the announcements concerning the APP program. We can see that some recalibrations of the APP had a significant effect in further lowering the GDP-weighted curve at longer maturities. Interestingly, the events that had the greatest impact on the long end of the curve were the announcements of the reduction in the monthly size of net purchases (December 2016 and October 2017) and their phasing out (June 2018). In contrast, the announcement of the restart of the programme in September 2019 had a predominantly positive impact on both YCs. One possible explanation is that markets may have expected a higher pace of monthly net asset purchases despite the accommodative nature of the open ended announcement.

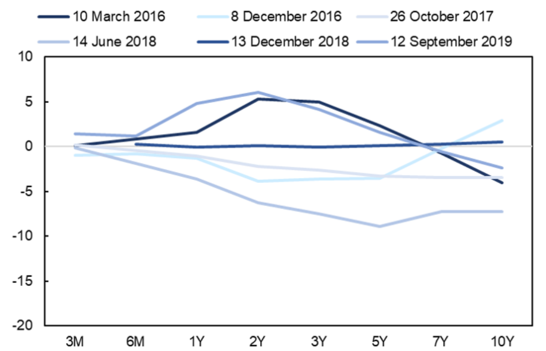
The OMT and PEPP recalibration announcements, shown in panels (c) and (d), had negligible effects on the OIS YC and some effect on the long end of the GDP-weighted curve. In contrast, the effect of the August 2011 SMP announcement is very sizable on both YC.

Figure 17: Changes in yield curves at announcements of unconventional measures

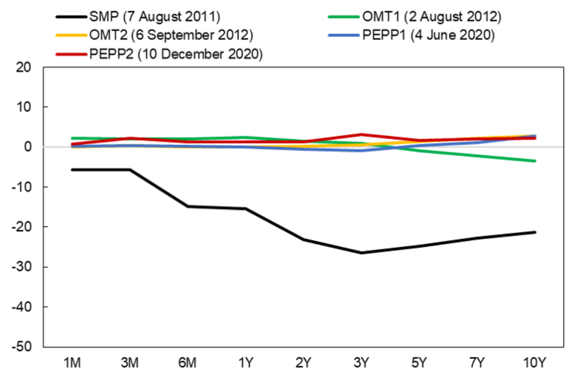
(a) EONIA - APP recalibrations



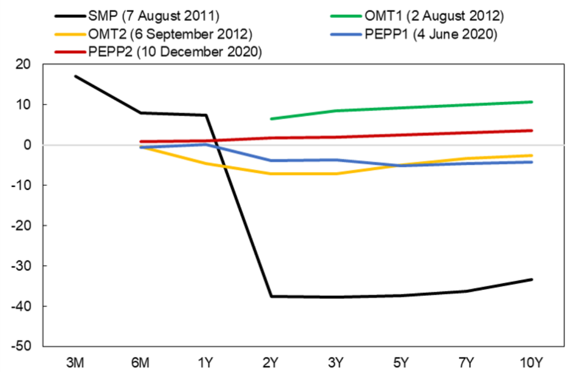
(b) GDP-weighted yields - APP recalibrations



(c) EONIA - other announcements



(d) GDP-weighted yields - other announcements



Sources: Reuters and authors' computations.