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Combining negative rates, forward guidance and asset purchases: identification and impacts of the ECB's unconventional policies

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Abstract

This paper provides new empirical evidence that bears on the efficacy of unconventional monetary policies when the main policy rate is negative. When a negative interest rate policy (NIRP) is deployed in concert with rate forward guidance (FG) and quantitative easing (QE), the identification of the impacts of these unconventional instruments of monetary policy is challenging. We propose a novel identification approach that seeks to overcome this challenge by combining a dense, controlled event study with forward curve counterfactuals that we construct using predictive rate densities derived from rate options. We find that NIRP has exerted a sizeable influence on the term structure of interest rates throughout maturities while, on net, the impact of rate FG has been more muted. QE explains the lion's share of yield effects, particularly over the back end of the yield curve. We then feed these rate counterfactuals into a large-scale Bayesian VAR and generate alternative histories for the euro area macro-economy that one would likely have observed between 2013 and 2020 in *no*-NIRP (*with* or *without* FG) and in *no*-QE regimes. According to this conditional forecasting exercise, in 2019 GDP growth and annual inflation would have been 1.1 p.p. and 0.75 p.p. lower, respectively, and the unemployment rate 1.1 p.p. higher than they actually were, had the ECB abstained from using NIRP, FG and QE over the previous six years or so.

JEL classification: C32, C54, C58, E50, E51, E52

Keywords: Monetary policy, Large-scale asset purchases, Negative interest rates, Forward guidance, Yield curve, Forward curve, Rate options

Non-technical Summary

The main contribution of this paper is to provide new empirical evidence that bears on the efficacy of unconventional monetary policies when the main policy rate is negative. We measure efficacy by the extent to which the unconventional policies have succeeded in making financial conditions easier than they would otherwise have been, and could thus stimulate growth, reduce unemployment and support inflation at times in which the economic recovery from the post-crisis recession was atypically restrained, and the central banks' traditional policy tool was unavailable.

When a negative interest rate policy (NIRP) is deployed in concert with forward-leaning guidance (FG) and an asset purchase programme of the type popularly known as quantitative easing (QE), the identification of the impacts of the three instruments, and particularly of FG, on financial prices and the macro-economy is challenging. We seek to solve this empirical challenge by embracing a novel identification approach and applying it to the ECB's unconventional policy history since 2013. We use a dense, controlled event study to identify surprises to the FG and QE policies (specifically, the ECB's Asset Purchase Programme (APP) initiated in mid-2014 and the Pandemic Emergency Purchase Programme (PEPP) introduced in March 2020) and quantify their impacts on different segments of the predictive distributions of the future short-term interest rate that we extract from rate options, and on the sovereign yield curve. We then construct counterfactual histories for money market forward rates and sovereign bond yields that would have been observed under alternative monetary policy regimes in which the ECB: would have observed the zero-lower-bound on its policy interest rates (a no-NIRP scenario); or would have issued no guidance on their future evolution (a no-FG scenario); or would have abstained from purchasing bonds on a large scale in the secondary market (a no-QE scenario). Finally, we feed these counterfactual rate histories into a large-scale Bayesian VAR to score the effects of the three policies on the macro-economy.

We find that NIRP has exerted a sizeable influence on the sovereign curve throughout maturities. The magnitude of the response in long-term interest rates to the NIRP impulse exceeds by a wide margin the extent to which long rates are seen to react to conventional policy cuts away from the lower bound. On net, the impact of rate FG has been more subdued. QE explains the lion's share of yield effects, particularly over the back end of the yield curve, If investors' prior expectations of upcoming QE recalibrations are accounted for, we estimate QE to have compressed the 10-year euro area average sovereign yield by more than 200 basis points since 2015.

These market impacts have translated into a measurable monetary policy impulse for the macro-economy. According to the conditional forecasting methodology that we employ to gauge the transmission of the three policies to real activity and inflation, in 2019 GDP growth and annual inflation would have been 1.1 p.p. and 0.75 p.p. lower, respectively, and the unemployment rate 1.1 p.p. higher than they actually were, had the ECB abstained from using NIRP, FG and QE over the previous six years or so.

1. Introduction and summary

The purpose of this paper is to use the methods of modern empirical finance and time-series macro-econometrics to assess the effectiveness of unconventional monetary policies when the policy interest rate is negative. Drawing on the ECB's nearly unique experience with combining systematic forward guidance (FG) on future settings of its policy rate and a massive programme of bond purchases (QE) with a negative interest rate policy (NIRP), we provide new empirical evidence that bears on the efficacy of these three instruments, jointly and individually. We measure efficacy by the extent to which these three unconventional policies succeeded in making financial conditions easier than they would otherwise have been, and could thus stimulate growth, reduce unemployment and support inflation at times in which the economic recovery from the post-crisis recession was atypically restrained, and substantial easing by the ECB's traditional policy tool was unattainable.

Analysts seeking to quantify the effects of a monetary policy action have to wrestle with a host of identification issues. One is about the endogeneity of monetary policy. Are those observed movements in financial prices or in the economy following a monetary policy action due to the policy intervention itself, or to other factors that spurred that intervention in the first place? It is only the component of monetary policy which is plausibly *exogenous* to the economic state that must be examined in order to gauge the causal effects of monetary policy on the economy.[1] A voluminous and growing body of research, pioneered by Kuttner (2001), and much advanced by Cochrane and Piazzesi (2002), Gertler and Karadi (2015) and Nakamura and Steinsson (2018a), has sought to address endogeneity through what has become known as a high-frequency identification approach. This method looks for exogenous, *unexpected* policy innovations by focussing on movements in bond and futures prices within a narrow time window – with a size from 30 minutes to 3 days – surrounding few selected policy events. It builds on a twofold assumption. First, financial markets are forward-looking and efficient, so any discrete jump in financial prices that is recorded in the short observation window around the policy event *must* reflect a surprise, i.e. an exogenous innovation. Second, the observation period is so tight that the confounding influence of non-policy factors on financial prices must be vanishingly small compared to the arrival of the pure policy news.

The wide adoption of the high-frequency event-study approach is testimony to its strengths as a way to isolate clean monetary policy shocks. Its main weakness lies in its built-in lack of memory. While a disproportionate amount of monetary policy news indeed comes discretely and in a lumpy way around scheduled policy events, so it makes a lot of sense to look around those events for policy innovations, a fair amount of it creeps in incrementally, and gets embodied in financial prices through a slow-moving

[1] Early attempts to control for endogeneity in a VAR setting have relied on regressing the policy interest rate on contemporaneous values of several variables (such as output and inflation), as well as several lags of itself and these other variables, then considering the residuals from this regression as exogenous monetary policy shocks and achieving identification by positing a recursive ordering. This approach has been criticised, however, for failing to capture all the endogenous variation in policy. For a critique to the traditional monetary policy identification approach in a VAR context see Nakamura and Steinsson (2018b).

adjustment process. This is either because investors tend to appreciate the implications of the latest monetary policy decisions for their investment environment only gradually, and adjust their buying or selling strategies with a lag;[2] or because a forward-looking public bets on future decisions long before these are communicated in formal announcements, and acts pre-emptively. Either way, policy announcements might be only the start of an adaptive process in the marketplace, or the resolution of an incremental expectations-building trend. But there is typically no such memory or forward-lookingness inbuilt in the high-frequency approach. Therefore, those financial surprises that one identifies upon announcements might exaggerate or under-estimate the effective impact of the central bank's actions.

Another complication is that the estimated dynamic responses of financial and economic variables to a monetary policy surprise are not invariant to the message that the public reads into the post-meeting statement and ancillary official communications. As demonstrated by Campbell *et al.* (2012), Nakamura and Steinsson (2018a) and Jarocinski and Karadi (2020), information effects might contaminate transmission. Perceptions that the central bank, in deciding to, say, ease its policy stance, might in fact be reacting to negative proprietary information about the present and future state of the economy can modify beliefs about economic fundamentals in directions that neutralise the stimulative effect of the policy decision. Said differently, the impact on bond yields that one registers around the event is no sufficient statistic for the message that the central bank intends to release in its policy pronouncement. Only the deliberate policy message – or, in the famous taxonomy proposed by Campbell *et al.* (2012), the "Odyssean" part of the central bank's communication about its policy intentions – qualifies as a clean policy shock.

The advent of a new season of monetary policy-making by unconventional tools has only made the identification issues that we refer to above more acute, and has added novel issues to the list. A major extra complication for those trying to identify monetary policy shocks has to do with the *multiplicity* of operating instruments in unconventional monetary policy times. In a seminal paper Gürkaynak *et al.* (2005) found that the effects of a given hike or reduction in the conventional instrument of monetary policy were high-dimensional even prior to the financial crisis.[3] What has changed since the crisis is that the instruments utilised to elicit those multidimensional effects have themselves become a plurality. Ever since late 2008, many central banks have been operating on multiple margins, trying to influence not only short-term, but also medium-term and long-term interest rates by pulling different levers, ranging from forward guidance, i.e. forward indications about the likely direction of their standard policy rates over the next several quarters, to bringing those standard policy rates to negative levels, to large-scale asset purchases, also known as quantitative easing. While these new instruments were each expected to operate

[2] In other words, the time that it takes for the piece of monetary policy news to reach those who can act on it is stretched and not concentrated around policy announcements. Greenwood *et al.* (2018) show that the process by which generalist investors move capital from one market to another in response to relevant news and arbitrage opportunities can take time, because of regulation or other impediments to aggressively trading across assets.

[3] In a US context, Gürkaynak *et al.* (2005) show that prior to the crisis, there appear to have been a *target factor*, which captured changes to the Federal Reserve's funds rate target, and a *path factor*, which captured information from the rest of the statement and had the largest effect on yields at the two-year maturity. More on this below.

on a particular segment of the yield curve, the preponderance of the evidence gathered so far shows that in fact the transmission patterns through the term structure of interest rates emanating from any one of those three instruments intersect, amplify and confound each other (see Rostagno *et al.*, 2019). The cross-externalities among unconventional policies are an unmitigated advantage for policymakers, because they tend to magnify the impact of each single tool. But they add one more headache for the econometrician.

A widely studied case is the interaction between forward guidance (FG) and quantity easing (QE). Several authors have found that QE affects the macro-economy to a large extent by changing financial markets' expectations about the future path of the policy interest rate (see Krishnamurthy and Vissing-Jorgensen, 2011, Christensen and Rudebusch, 2012, and Bauer and Rudebusch, 2014). The idea behind this proposition is that the large balance sheet that QE brings with itself provides a strong incentive for the central bank to maintain a highly expansionary policy for a longer period of time than it might otherwise have desired, perhaps in a bid to avoid the losses that raising rates prematurely would cause on the assets it owns. But then, to the extent that such a "signalling channel" is an important element of a QE programme, the mechanism by which QE transmits is hardly recognisable in a world in which the central bank also deploys FG to send signals about the likely path of its policy rate moving ahead. The difficulty of separately identifying the effects of the two policies is further aggravated by the fact that announcements regarding one policy typically provide information about the other policy simultaneously.[4]

Swanson (2020), building on his prior work in Gürkaynak *et al.* (2005), has put forward an ingenious identification strategy to extricate the effects of FG and QE announcements in a zero lower bound (ZLB) environment. The method – applied, among others, in Rogers *et al.* (2018), Bu *et al.* (2020), Altavilla *et al* (2019), Kim *et al.* (2020) – relies on the observation that in principle these two policies affect the entire yield curve, but do so differently at different points on the term structure.[5] If QE is intended to extract

[4] In monetary policy regimes in which the central bank controls the overnight money market interest rate via a rate corridor system, there is a further connection between FG and QE. FG indications about the future path of the corridor do not necessarily translate into precise indications about the likely path of the overnight interest rate, so long as the overnight rate – which anchors the entire term structure of money market interest rates – can fluctuate freely within the corridor. A QE programme saturates the money market with the surplus of liquidity that is necessary to keep the overnight rate permanently close to and controllable by the floor of the corridor. This is a necessary condition for FG on the future path of the rate corridor to be able to influence expectations of the future path of the market overnight rate.

[5] Swanson's identification procedure applies to pre-crisis as well as post-crisis times and is more elaborate than in our description. More specifically, he computes the first three principal components from the intraday interest rate changes observed in a short window of time bracketing FOMC policy announcements from 1991 to 2015, and rotates them into three latent factors that can be associated with a federal funds rate target, FG, and QE actions by imposing that both the FG and QE factors have zero effect on the current-month federal funds futures and that the magnitude of the QE factor over the pre-crisis period (from 1991 to December 2008) is minimized. As shown in Swanson (2020), this procedure can be approximated with great precision by using a simpler orthogonalisation approach, whereby one defines "QE surprises" the residuals from a regression of the change in the 10-year yield onto "FG surprises", and defines "FG surprises" as the residual from a regression of the change in an intermediate-maturity interest rate – say, the 2-year Treasury yield – onto the policy rate surprises. In a ZLB world, policy rate surprises are nil. We follow a similar orthogonalisation logic in what follows.

duration risk from private hands, then its effects will manifest themselves in reductions of duration risk reward on long-dated assets,[6] because these assets are the most exposed to interest rate variation and thus to that type of risk. So, as documented by many studies (Gagnon *et al*, 2011, and Altavilla *et al.*, 2015, among others), QE will primarily bear down on yields at the back end of the yield curve. Conversely, if FG is a tactic to communicate a lengthening of the anticipated period of time over which short-term interest rates are likely to remain constant at very low levels, then the later date at which investors will anticipate a policy rate lift-off following a FG communication will translate one-to-one into lower interest rates over those intermediate maturities that are most affected by policy rate expectations. Indeed Gürkaynak *et al.* (2005) showed that the "path component" of monetary policy communication – a shock that even prior to the crisis could be associated with the forward-looking part of policy statements – leaves a hump shaped imprint on the yield curve, with peak effects at 2 to 5-year tenors. Swanson (2020) looks at the immediate effects of FOMC post-meeting announcements on financial prices and applies this logic to categorise monetary policy news pertaining to the two unconventional instruments utilised by the Federal Reserve, QE and FG. Any factor in the central bank's policy release that is detected to flatten the mid- to far-out maturity segment of the yield curve must be related to QE news. Any factor that flattens the short- to mid-maturity segment of the curve must be related to an (easing) FG innovation. Finally, any news that were to move the very short end of the curve, e.g. within a month horizon, would signal a change in the policy rate itself. In ZLB conditions, the latter factor is absent, because the federal funds rate – the Federal Reserve's traditional operating target – has remained constant in the vicinity of zero for much of the post-crisis period, so the analysis can conveniently concentrate on FG and QE.

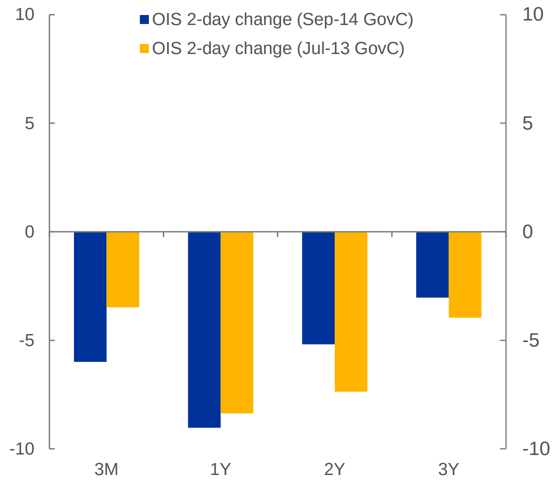
While Swanson's procedure to track down QE shocks can be widely generalised, his approach to isolating FG shocks cannot be readily applied in regimes in which the policy rate has been taken to negative levels. Here is where a negative interest rate policy (NIRP), of the kind the ECB adopted in 2014 as part of a wider plan to ease credit conditions, adds one extra layer of complexity to the econometrician's job. The descriptive evidence provided in Figure 1, drawing from the ECB's experience, helps understand why. Essentially, a cut in negative ground doesn't propagate through the yield curve quite in the same way as a traditional equally-sized cut from and to a non-negative level. Instead, its transmission through the yield curve bears a very close resemblance to the transmission of a typical FG

[6] Both the Federal Reserve and the ECB have justified their massive asset purchase programmes (QE) by invoking a duration extraction channel. This channel is ruled out in many standard economic models, including in much of the arbitrage-free fixed-income finance literature in the Cox *et al.* (1985) tradition, but could arise under some formulations of preferred habitats or other market imperfections (see, for example, Vayanos and Vila, 2021). According to this view, investors averse to interest rate volatility require higher expected returns to buy-and-hold a long-dated security, relative to a strategy of rolling over short-term securities paying the very short-term interest rate for the whole life of the long-dated security. The longer the duration of an asset, the higher the interest rate risk (or duration risk) to which the investor is exposed, the larger the duration risk reward the investor will demand to hold the asset. If a central bank under QE absorbs a large portion of the outstanding stock of long-dated securities, and warehouses them in its buy-and-hold portfolio, the quantum of duration risk outstanding for the market to hold diminishes. This makes some of risk tolerance available in the marketplace that would otherwise be soaked up bearing duration risk free to bear other kinds of risk, including on productive capital. With more risky enterprises being undertaken, the level of economic activity should increase.

shock: it gives rise to the same hump-shaped term structure of impacts.[7] The picture shows the shifts in the overnight forward curve – a market measure that encapsulates rate expectations – at different maturity points, following a pure NIRP shock (blue bars) and a FG shock (yellow bars). The pure FG shock refers to the ECB's first foray into verbal guidance on July 4th 2013. On that day, the Governing Council of the ECB announced that it expected "*the key ECB interest rates to remain at present or lower levels for an extended period of time*." The statement was qualitative and unspecific. Nevertheless, markets immediately took note that a serious discontinuity had occurred in the official communication practices of a central bank that had traditionally made the pledge to never pre-commit. The pure NIRP shock came on September 3rd 2014, when the ECB unexpectedly cut its deposit facility rate – the steering interest rate in the de facto floor system that the ECB has been operating virtually since the financial crisis – for a second time by 10 basis points to -0.2%. Watching how markets reacted to that decision is particularly informative because the ECB's NIRP action was unexpected, and because that is the only instance at the time of writing in which an ECB NIRP action could be observed in isolation, i.e. not as part of a broader package of monetary policy decisions. The two patterns look qualitatively the same: for both measures, it is mid-maturity interest rates that load most heavily on the shock.

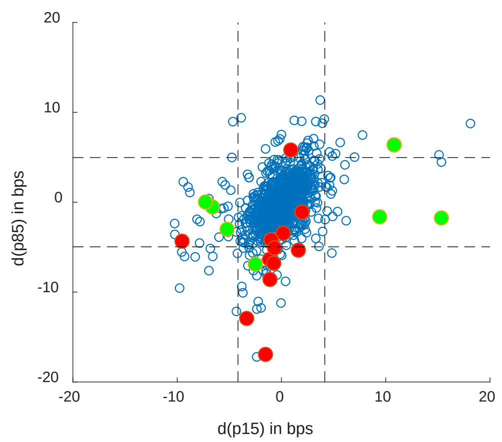
Figure 1: Expectations of short-term interest rates around NIRP and FG events

Figure 1.1: Two-day changes in 3M OIS forward rates on 04/09/2014 and 04/07/2013 *(basis points)*



Sources: Refinitiv and ECB calculations.
Notes: Two-day changes in 3M OIS forward rates for horizons of 3M to 3Y.

Figure 1.2: Two-day changes of 15th vs 85th percentile of option-implied 3M Euribor density 12 months ahead *(basis points)*



Sources: Refinitiv and ECB calculations.
Notes: Each dot is a pair of the two-day change in the 15th and 85th percentile of the predictive risk-neutral distribution of 3M Euribor 12 months ahead derived from options. Dots represent all two-day changes from 1 Jul 2013 to 31 Dec 2019. Green dots relate to NIRP events (5 Jun 2014, 4 Sep 2014, 21 Jan 2016, 29 Jan 2016, 10 Mar 2016, 27 Mar 2019, 12 Sep 2019), while red dots represent FG events (the dates listed in Table 2 below).

[7] For instance, Altavilla *et al.* (2019) and Rostagno *et al.* (2019) document a hump-shaped response of the euro area term structure to a FG shock. Swanson (2020) finds a similar term structure pattern in response to the Fed's forward guidance.

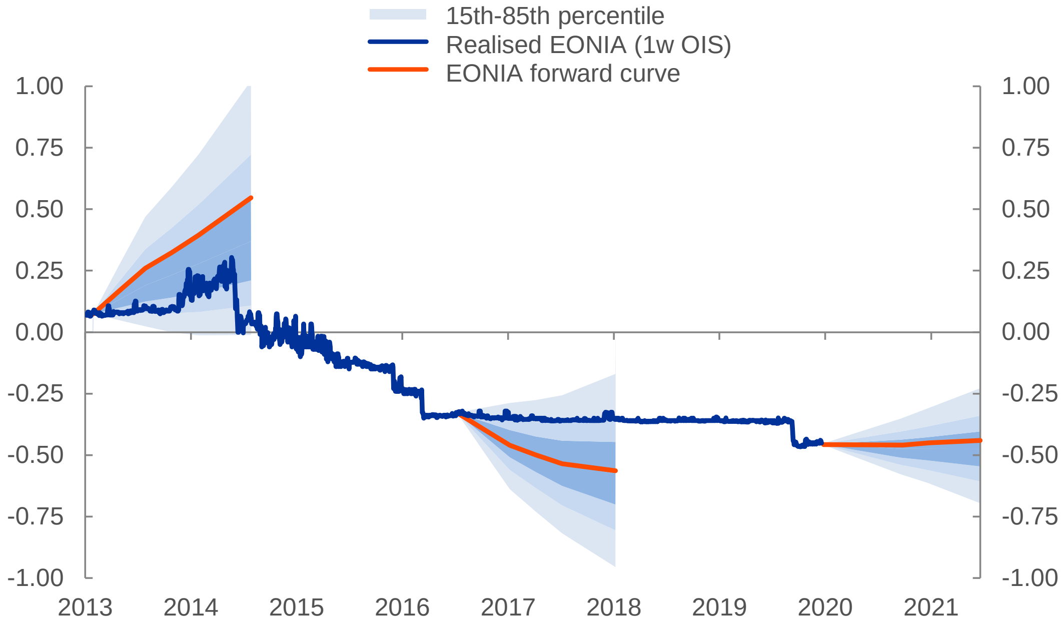
Why does NIRP masquerade like FG? In Rostagno *et al.* (2019) we show that in ZLB conditions market expectations of future short-term rates demonstrate a marked upward tilt, as the conditional distribution at any time t of all plausible rate paths up to h periods ahead is censored at zero, with a possibly bulky probability mass assigned to zero-rate realisations and some residual probability placed on realisations above a zero rate. However, NIRP shatters the notion that zero is the lower bound on short-term rates. By doing so, it restores the possibility that, looking into the future, rates might move in both directions, up or further down.[8] To the extent that a NIRP action reasserts this symmetry, it stands to reason that the measured effects of a NIRP decision will be most pronounced over the short- to medium-term portion of the forward curve. Alas, these are also the tenors over which a FG surprise exerts maximal impact. Hence the commonality we see in Figure 1. Whatever the interpretation of this evidence, the upshot is that an Odyssean FG pronouncement, deliberately meant to ease monetary conditions by narrowing term spreads, is generally not distinguishable – just observing its market implications – from a similarly Odyssean release of information received by the market as a signal that the central banks might cut its steering rate to a (more) negative level. From an econometric standpoint, the lack of sharp differentiation between the two policies precludes Swanson's well-travelled strategy to uniquely identify a FG shock in a NIRP world.[9] Said differently, applying to a NIRP world the identification strategy employed by Gürkaynak *et al.* (2005) and Swanson (2021) to separate out a target shock from a FG shock would not allow correctly identifying the relative contribution of NIRP and FG policies. The reason is that such a strategy would assign any movement of the short-to-medium-term segment of the forward curve at unchanged current short-term rate to FG (or QE). But dips of the forward curve below zero would not happen absent a NIRP world.[10]

[8] See also see Ruge-Murcia (2006). Another reason we mention in Rostagno *et al* (2019) for the pronounced impacts of NIRP over medium-term and even long-term interest rate is that the negative-rate fee imposed on liquidity under NIRP drives banks and other investors to longer-maturity assets in a bid to avoid "being taxed" on their liquidity balances. Banks' aggregate reserves with the central bank continue to be taxed. But the result of such transactions by individual banks and other investors is that the term premium on longer-term assets is suppressed. Incidentally, the evidence of these NIRP effects – both those reflected in the expectations part of long-term rates and those reflected in a lower terms premium – significantly weakens the argument that policy rate reductions in negative grounds can be effective only to the limited extent that they finesse the ZLB and afford some modest extension of the scope for conventional rate policy. See, among others, Greenlaw *et al.* (2018).

[9] In evidence not shown but available from the authors, we show that those shocks that we identify as FG or NIRP surprises lead to much the same extension of the time to rate lift-off implicit in the forward curve.

[10] This means that the policy space available for FG is larger in presence of a NIRP world. This additional policy space bought by a NIRP world should be considered as pertaining to NIRP. Otherwise, FG would be considered to have a power that in reality does not have absent a NIRP world.

Figure 2: Eonia rate, Eonia forward rates and risk-neutral distributions on selected dates *(percentages per annum)*



Sources: Refinitiv and ECB calculations.
Notes: The risk-neutral option-implied densities for future Eonia (3M OIS, obtained from the density for 3M Euribor by subtracting the 3M Euribor – 3M OIS spread) are given by the blue fan chart around the red solid line representing the Eonia (3M OIS) forward curve. The dates of the selected Eonia forward curves are 29 January 2013, 08 July 2016, and 20 December 2019.

A finer map of investors' views about the outlook for interest rates than is crystallised in the forward curve can help better discriminate between the two policies. From the prices of options on interest rate futures, for example, it is possible to construct the entire probability distribution (PDF) for the very short-term interest rate in the future, i.e. the risk-neutral likelihood that investors ascribe to all paths that the very short rate may plausibly follow looking ahead. There is one such PDF per trading day, and the daily forward curve derived using conventional techniques can be viewed as the probability-weighted average of all the likely paths that form that PDF. Figure 2 shows a selection of such PDFs portrayed as fan charts: they are all pinned at the overnight interest rate – the so-called Eonia index, whose time series is represented by the thick blue line – and, at each point in time, they project the whole spectrum of markets' views about the likely direction of the overnight rate and the policy rate over the next 18 months. Due to the unavailability of option contracts with a maturity longer than 18 months, the fan charts shown in Figure 2 cannot span horizons beyond six quarters ahead. Inspection of how different regions of those daily PDFs change in response to NIRP- and FG-types of announcement, respectively, turns out to be instructive. The right panel of Figure 1 shows a cloud of points, each of which corresponds to the two-day change recorded in the lower 15th percentile (horizontal axis) and upper 85th percentile (vertical axis) of the options-derived rate PDF on a wide selection of dates in our sample. The red dots are associated with those dates in our grid of policy news events which we categorize as "FG events" (see below). The green dots represent events that have a strong NIRP connotation. By and large, red dots tend to cluster along a North-South axis, with the South quadrant comprising dates in which the FG message was received as accommodative by the markets. The green dots are more dispersed, but display a recognisable pattern of lining up on a West-East axis.[11] Essentially, both NIRP and FG innovations move intermediate-maturity forward rates, but do so differently. An FG shock is associated with a larger shift in the upper quantiles of the distributions shown in Figure 2, with little to no adjustment in the lower percentiles, while episodes in which the NIRP-relevant content of the event is dominant more often than not move the lower portion of the distribution and leave the upper part nearly unchanged.

This regularity is economically interesting, and – we believe – empirically helpful in overcoming the NIRP-FG identification issue. The economics of it is compelling. If FG is meant to shift the expected time for the onset of tightening of monetary policy progressively further into the future, then indeed one should expect to see its effects most clearly in a flattening of those expected rate paths within the predictive rate distribution that, in the representation of Figure 2, hover above the forward curve. Arguably, those are the paths embraced by *optimistic investors* who believe that the central bank, no matter what it might say today, will be forced by a better macroeconomic outlook than currently predicted by the average investor view to increase its policy rate earlier than it promises to. FG is successful to the extent that it persuades some or all of those optimists – in fact, *FG sceptics* – to revise their views. If successful, FG should therefore reduce the upward uncertainty surrounding the rate path that the average investor – the one subscribing to the forward curve – considers most likely. Conversely, a NIRP surprise speaks more directly to the *pessimists*. These are investors who, already before the announcement, were betting on circumstances that would necessitate an even lower path for the policy rate than embedded in the forward curve. They are most reactive to any news that can shift their perceptions about the location of the ELB.

With this in mind, we exploit the regularity depicted in Figure 1 and Figure 2 to identify shocks to the ECB's FG strategy, and we build on the same evidence to inform the construction of counterfactual worlds in which the ECB would have made no use of NIRP. In the remainder of this section, we outline our methodology to assess the effectiveness of NIRP, FG and QE in changing financial conditions and the course of the macro-economy. The methodology we use to arrive at our conclusions has three stages: identification of the FG and QE shocks, the construction of rate counterfactuals, and finally the construction of macroeconomic counterfactuals.

Identification of FG and QE shocks

In the identification stage, we adopt a controlled, dense-event-study approach to try and tease FG and QE surprises apart. Specifically, we select a larger than usual, dense population of policy events around which we observe interest rate changes, including all those dates in which the ECB demonstrably chose to signal its intentions regarding the earliest date of a rate lift-off, or to provide incremental information

[11] The two dots in the East quadrant correspond to two episodes of post-meeting ECB communication: one (September 12th 2019) in which the market – having forecast a deeper cut – was disappointed by the size of the rate action delivered by the Governing Council; and another one (March 10th 2016) in which unscripted remarks by the ECB President in the post-meeting press conference were interpreted as closing the door to further interest rate reductions to more negative levels.

about the size and modalities of its QE programme. The set includes official post-meeting statements as well as key speeches delivered by the ECB's President. In an attempt to discern the clean Odyssean message that the central bank wanted to hammer home with those announcements, we seek to control for the market repercussions of any coincidental disclosure of the ECB's views about the state and likely evolution of the economy. For this, we construct revisions of ECB's macroeconomic projections – published four times a year on the day of the monetary policy meetings of March, June, September and December. We also control for the daily arrival of euro area and US macroeconomic news, which can at times move market rates measurably, and for the general liquidity conditions prevailing at each point in time, which can influence rate volatility. Finally, and importantly, we allow for the gradual build-up of policy expectations. In view of the pivotal role the ECB assigned to its asset purchases in the early phase of the programme (see the next section), we proxy the mechanism by which markets have kept updating their expectations of future policy (re)calibrations with a new measure of the stock of bonds that investors, at each point in time, were anticipating the ECB would accumulate eventually in its QE portfolios. For this purpose, we compile a new time series of expected increases in the ECB's balance sheet size related to QE foreseen by market participants and extrapolated using survey information.

In terms of the mechanics of our identification stage, we run regressions in which daily rate changes on the left side of the equation are related to a number of regressors on the right side, including a series of time dummies, one for each policy news event we consider, the ECB's projections surprises, the Citi macroeconomic surprise index for the euro area and the US, the CISS indicator of market stress, and our measures for the expected QE portfolios. To identify FG shocks, we build on the evidence shown in Figure 1, and we use as the left-hand variables various quantiles of the PDFs derived from options on future short-term interest rates at the 12-month and 18-month horizon, which we construct for each trading day in our sample. As we argue above, the upper sections of the rate PDF (illustrated for the 12-month horizon in Figure 1.2) are those where FG innovations tend to leave their characteristic imprint. In quantifying the contribution of FG on the daily changes in the 12-month- and 18-month-ahead quantiles, we orthogonalise the forward guidance innovations to any change that might have coincidentally occurred in the very front end of the term structure by adding the 3-month overnight indexed swap (OIS) spot rate to the right-hand side, so as to purge the estimated shift in the upper quantiles from any residual effects caused by NIRP action. To identify pure QE shocks, the left-hand variable is the daily change in the euro area sovereign yield at different maturities.[12] Mirroring the orthogonalisation approach followed for the FG identification analysis, we add the 3-month spot OIS rate and the 3-month in 12-month forward rate as two extra right-hand variables to clean the estimated QE effects on the long-term sovereign interest rate of any NIRP or FG factors.

To arrive at a time series of FG and QE shocks, we adopt an accounting approach. First, we sort our population of events by the degree to which each of them was informative for shaping FG or QE

[12] The interest rates on the euro area sovereign are obtained using the Svensson's smoothing methodology (data are available on the ECB website).

expectations, respectively. This selection is primarily based on the content of the official statements, but we also validate the selection in two ways. We observe the reaction of the term structure of interest rates to the event news: an upward-sloping term structure of impacts across maturities underscores a strong QE signal; a hump-shaped term structure is consistent with a FG-type surprise. As a further check, we construct an indicator that measures the daily frequency of business media coverage with a focus on euro area FG or QE, and test whether and which of the two indicators spikes on the date of the event.[13] By this dual test, we document that – barring a handful of episodes in which the policy announcement disappointed prior expectations – over the years there appears to have been a relatively tight alignment between the intentional policy message and the market reception. At the end of this selection process we identify two subsets of events: those of a FG type and those of a QE type.

The second component of our accounting methodology to keep track of the effects of FG and QE (re)calibrations is related to the term in the regressions that quantifies markets' evolving views about the steady-state stock of the ECB's QE bond portfolios. These expectations tend to grow over time and bid down interest rates incrementally well ahead of a (re)calibration event. For QE, we count those front-loaded interest rate changes toward the cumulative effect of the final announcement, together with the market reaction to the eventual announcement itself. If markets had over-predicted the bond programme augmentation in the run-up to the announcement, the anticipated effect will be curtailed by the effect of the final market disappointment. If expectations had been too conservative, the final surprise will top up the rate effect produced by the anticipations.

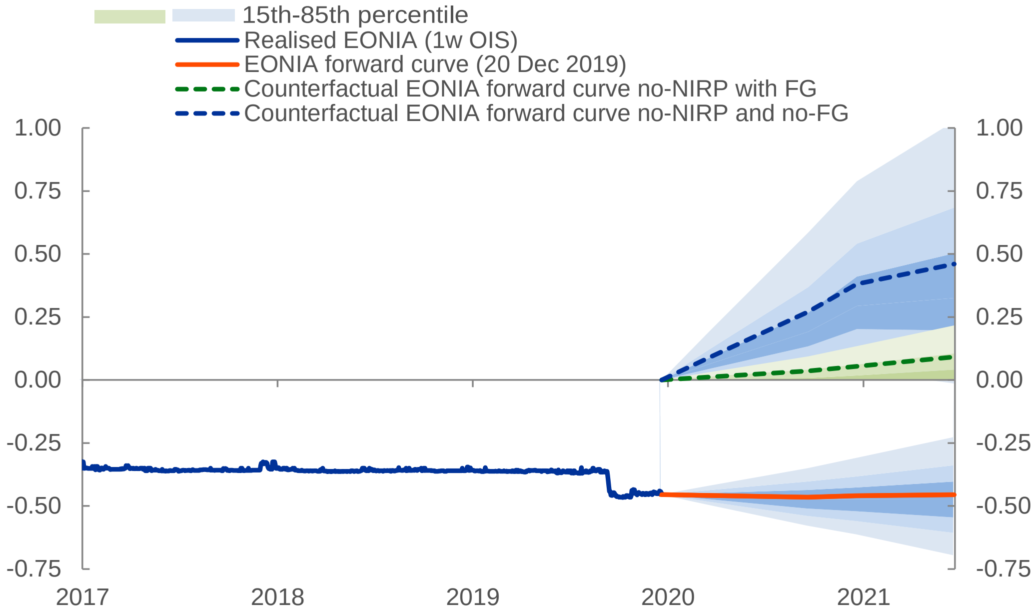
Rate Counterfactuals

With the identified FG and QE shocks in hand, we proceed to the construction of rate scenarios. In this stage of our methodology we manufacture hypothetical, counterfactual worlds in which the ECB would have abstained from enforcing NIRP (in what we call a *no*-NIRP scenario), would have made no recourse to FG (*no*-FG scenario), or would have avoided QE (*no*-QE scenario), and we re-write the history of the euro area interest rates in those three worlds.

The *no*-QE counterfactual is comparatively straightforward to construct. Since our metric for the QE expectations coincides by construction with the central bank's announced plan for bond holdings on the dates of the announcements, we can cumulate the yield change that can be imputed to the building up of expectations in the run-up to each round of QE (re)calibration and the yield changes recorded on the dates of the announcements to arrive at an estimate of the extent to which, at each point in time, QE has altered the history of government yields. The sum of the actual yield time series and those (positively signed) QE contributions is our *no*-QE counterfactual.

[13] The main sources are Dow Jones Newswires, Reuters, WSJ, The Times U.K. The media coverage refers to a report, a commentary, a recap of the main news of the day, a newspaper article.

Figure 3: Eonia forward rates and risk-neutral distributions: history and no-policy counterfactuals *(percentages per annum)*



Notes: Eonia (1-week OIS) path (blue line) and OIS forward curve of 20 Dec 2019 (red line), together with option-implied risk-neutral distribution (blue fan chart at the bottom). The middle green fan chart represents a counterfactual no-NIRP with FG scenario, while the upper blue density represents a no-NIRP, no-FG scenario. See the main text for details.

A *no*-NIRP scenario is defined as a policy regime in which, referring to Figure 2: i) the overnight interest rate would have remained pinned at zero rather than fallen to a sub-zero level – where in fact it has been since mid-2014 (see the dark blue line); ii) investors would have placed no probability mass on any future rate path involving a negative overnight rate over the next 18 months, i.e. the predictive densities shown in Figure 2 would have been all censored at zero – as they indeed were prior to the time in which the ECB inaugurated its NIRP; iii) the *pessimists* among those investors – i.e. those foreseeing an interest rate trajectory lower than that embedded in the forward curve – would not have been any more upbeat over the economic prospects and the likelihood to see higher rates at least up to a horizon of 18 month ahead. Consequently, the ZLB would have acted as an absorbing state for all the rate trajectories expected by those investors; iv) the *optimists* – those expressing future rate bets above the forward curve – would have remained sensitive to FG, as we show they have been in reality (remember Figure 2).

In essence, we quantify the contribution of NIRP to the history of forward rates in something similar to an *in vitro* laboratory experiment. We artificially create a world in which the central bank would have chosen not to violate the ZLB in setting its policy rate, and market participants accordingly would have had no memory of a negative nominal interest rate, and would have anticipated no such an event occurring in the future. Reflecting these assumptions, we re-anchor the entire sequence of the rate PDFs in our sample to a zero overnight rate, we re-apportion any density mass in those displaced PDFs falling below zero to zero, and we condition the density mass remaining above zero on whether the *no*-NIRP world would have been one *with* FG or *without* FG. We illustrate the exercise in Figure 3. As an example, we zero in on the PDF associated with the last trading day of 2019 for which the density data is available, (the lower blue fan on the right of the picture, which coincides with the rightmost fan shown in Figure 2). The exercise has two parts:

- After re-anchoring and censoring the historical density, we arrive at the green distribution in Figure 3. We think of the green distribution as one representative of a world of "*no*-NIRP *with* FG". The reason is that the upper region of the distribution – the portion that most sensitive to FG – incorporates precisely the same doses of FG that the ECB offered in history. As apparent in the chart, the counterfactual forward curve associated with the displaced, censored counterfactual density (the green-dashed line) is distinctly steeper than the actual, primitive forward curve (the red line). The difference between the two forward curves is our summary statistic for the impact of NIRP, as a standalone unconventional policy instrument, on the forward rates with tenors up to 18 months.
- How impactful have those historical doses of ECB FG been over the years in shaping markets' views about the future course of the short rates? The identification stage of our exercise extracts precisely the time series of effects of the ECB's FG interventions on the rate distribution, which we can utilize to simulate how a world without those interventions might have appeared. This is indeed the way in which we generate the rate distribution that one would have observed in a "*no*-NIRP / *no*-FG" world. Such a distribution, which we report as the blue fan on top of the green one in Figure 3, is derived by purging the green distribution from the estimated effects of the type of FG formulation that was prevailing at the end of 2019. The difference between the forward curve represented as a blue-dashed line and the green-dashed line is our measure of the impact of FG on the forward curve to up an 18-month maturity.

Macro Counterfactuals

The alternative histories of the euro area term structure of interest rates that one would have observed under a ZLB policy, with or without FG, and in a *no*-QE world are then simulated using a macroeconometric model of the euro area to arrive at the corresponding counterfactual paths that the economy would have likely been on under those alternative policy regimes. We are agnostic about the precise mechanisms by which these policies may influence economic behaviours and agents' expectations. In support of these instruments as reflationary tools, we can only confidently point to the fact that, historically, exogenous, unexpected declines in the level of interest rates have tended to be associated with an ensuing resurgence of growth and upside price pressures. In line with this simple heuristic, we use a large-scale vector autoregression model of the euro area, in which the curse of dimensionality problem is controlled through Bayesian shrinkage, as suggested in De Mol, Giannone and Reichlin (2008). In particular, we feed the counterfactual history of forward curves – the '*no*-NIRP/*no*-FG' and the '*no*-NIRP *with* FG' configurations – and the counterfactual history of sovereign yield curves – in the '*no*-QE' hypothesis – into the B-VAR, where we can interact them with a wide spectrum of financial prices and with the macroeconomic state. The model includes 17 variables: real GDP, the rate of unemployment, HICP inflation, loans to non-financial corporations, loans to households, the Eonia, the 3-month Eonia forward in 12 and 18 months, the 2- 5- and 10-year euro area sovereign yields, the lending rate on loans to non-financial corporations and households, the interest rates applied on deposits of non-financial corporations and households, a stock market index, and the value of the euro vis-à-vis the US dollar.

The estimation of the impact of the ECB's unconditional policy measures on real, nominal and financial variables is carried out through conditional forecasting. This is done by comparing a no-policy scenario with a policy scenario. The no-policy scenario is simply obtained by running at each point in time between July 2013 and end-2019 the unconditional forecast of the B-VAR model. In the policy scenario, the paths for the policy-related variables that we have generated at the rate counterfactual stage of our methodology are considered the conditioning variables for the macroeconomic counterfactual simulations. The remaining fast-moving endogenous variables are allowed to respond contemporaneously. The set of slow-moving macroeconomic variables, including real GDP, unemployment, inflation and lending volumes, do not react to the policy on impact, but only over time. This set of restrictions are similar to those used in the literature on the impact of monetary policy shocks identified by imposing a recursive scheme, in which macroeconomic variables such as economic activity and inflation are not allowed to jump contemporaneously as the policy instrument is adjusted. Why do we prefer conditional forecasting over alternatives which also identify monetary policy shocks in a VAR setting using, like we do, extra-model information? One such alternative, for example, could have been achieving identification in our VAR with external instruments, an approach pioneered by Stock (2008), Mertens and Ravn (2013) and Gertler and Karadi (2015). And indeed we see merits in seeking to condense the causal inference gathered over our observation period in a "typical" response of interest rates to a "typical" unconventional monetary policy action (a NIRP, or FG, or QE innovation, as the case may be), which is the approach taken when generating impulse responses to a monetary policy shock identified via external instruments. However, we also believe that trying to characterize the world one would have lived in if *that* particular sequence of policy decisions had not been taken adds valuable information. This is particularly true in a context – like the ECB's – in which arguably there has been considerable time variation in the way each (re)calibration of policy was framed in official communication and received by the public. Building on this observation, one might well question whether there has been enough commonality in the shocks observed in history to justify the identification of a "standard" NIRP, FG or QE shock. This is why, we believe, our conditional forecasting approach has a lot of appeal.

We find that NIRP has exerted a sizeable influence on the sovereign curve throughout maturities while the overall impact of rate FG has been more subdued. The magnitude of the response in long-term interest rates to the NIRP impulse exceeds by a wide margin the extent to which long rates are seen to react to conventional policy cuts away from the lower bound. QE explains the lion's share of yield effects, particularly over the back end of the yield curve. We estimate QE to have compressed the 10-year euro area average sovereign yield by around 200 basis points since 2015.

These market impacts have translated into a measurable monetary policy impulse for the macroeconomy. According to the conditional forecasting exercise that we conduct to gauge the transmission of the three policies to real activity and inflation, in 2019 GDP growth and annual inflation would have been 1.1 p.p. and 0.75 p.p. lower than they actually were, respectively, had the ECB abstained from using NIRP, FG and QE over the previous six years or so.

Robustness

The robustness of our approaches and results can be tested along two main axes. First, the construction of *no*-NIRP counterfactuals is unconventional. Why not using a shadow-rate arbitrage-free term structure model to simulate the rate implications of re-imposing the ZLB in the construction of a *no*-NIRP world? Variants of shadow-rate models have been studied inter alia by Kim and Singleton (2012), Krippner (2013), Christensen and Rudebusch (2012 and 2015), Wu and Xia (2016 and 2020) and Lemke and Vladu (2017) and have become the workhorse representation of yield curve dynamics when rates are constrained by a lower bound, zero or negative. In Section 6 we argue that the reasons militating in favour of our counterfactual-based approach to gauging the impact of NIRP are compelling. Nevertheless, in that Section we conduct a robustness check on our approach using the shadow-rate model described in Lemke and Vladu (2017). We show that our preferred estimates for the impacts of NIRP are moderately larger than those that we obtain from the shadow-rate model, and we provide an intuition for the difference in inferences.

The second test to which we want to put our results concerns the design of rate and macroeconomic scenarios in general. Note that, regardless whether *with* or *without* FG, the counterfactual series of the censored PDFs, the object from which we depart to construct a "*no*-NIRP" world, quite mechanically, average to a series of forward curves invariably steeper than those observed in history. In the *no*-FG subcase, the predicted path of rate increases would have been particularly quick and steep (see the dashed-blue line in Figure 3). One might therefore wonder whether some or all of the market participants gambling on such steep rate trajectories might have tempered their optimism in the counterfactual macroeconomy – one with lower growth and weaker inflation – that would likely have materialised if the overnight rate had been stuck at zero and the central bank had been reticent about plans to keep it there over the next few quarters. We take up this objection in Section 6. We do so by using an iterative simulation strategy. We conclude that, on the face of it, the estimated macroeconomic impacts of NIRP and QE that we derive from our preferred methodology might entail a modest upward bias. We explain, however, why we view the counterfactual rate configuration that the iterative procedure leads to as unrealistic. This strengthens our confidence in the impact analysis that constitutes the core of this paper.

The paper is organised as follows. The next section provides a summary of the unconventional monetary policy strategy followed by the ECB since its first experimentation with rate FG in July 2013. Section 3 presents the event study methodology and results that we use to score the quantitative impacts of the various rounds of (re)calibrations of NIRP, FG and QE on the term structure of interest rates (the sovereign yield curve and the short- to medium-term maturity segments of the OIS forward curve). In Section 4 we explain how we construct counterfactual interest rate histories reflecting three alternative policy regimes: a no-QE, a "no-NIRP *with* FG" and a "no-NIRP / no-FG" scenario. Armed with those counterfactual rate paths, in Section 5 we explain how we feed them into our BVAR model to obtain the main results of this paper: the time series of the effects of three instruments on the macro-economy since 2013. Section 6 is devoted to illustrating the results of two robustness exercises, and Section 7 concludes.

2. A short history of the ECB's unconventional policies

The ECB grappled with the early phases of the global financial crisis principally by deploying lender-of-last-resort instruments. In response to the market meltdown and banking crisis that followed the demise of Lehman Brothers, the ECB granted credit institutions unlimited access to central bank liquidity at a fixed rate, and lengthened the tenor of the longer-term lending operations made available to its bank counterparties. This shift in its traditional operating framework helped to support economic activity during 2009 and early 2010 to some degree by enhancing the flow of credit and by increasing the public's confidence in the banking system. Later, when confronted with acute dislocations in the euro area sovereign bond markets that threatened to spiral into full-blown debt runs, the ECB helped restore confidence in those markets by engaging – or pledging to engage – in targeted sovereign debt purchases. From May 2010 to June 2012, the ECB made bond purchases under its securities markets programme (SMP), and in August-September 2012 announced details of an outright monetary transactions (OMT) programme to quench the market panic that had been touched off by fears of a near-term dissolution of the monetary union. While lender-of-last-resort programmes contribute indirectly to improved economic outcomes, in this paper we focus on non-standard monetary tools that *by design* were aimed at achieving inflation and macroeconomic objectives. This narrows the focus of our analysis down to the three instruments mentioned before: NIRP, FG and QE.[14] Table 1 provides a chronology of the ECB's Governing Council decisions that instituted and sequentially recalibrated the three instruments since July 2013. We refer to Rostagno *et al.* (2019) for a comprehensive overview of all the ECB's unconventional instruments – including the liquidity operations announced between 2008 and 2014 –, their history, motivation and impacts.

[14] Targeted Long-Term Refinancing Operations (TLTROs), launched in June 2014 (TLTRO-I), and re-calibrated sequentially in March 2016 (TLTRO-II), March-September 2019 and April-December 2020 (TLTRO-III) were designed to preserve bank-based transmission by offering banks long-term central bank credit on terms and conditions made dependent on banks' lending performance.

Table 1: Chronology of the ECB's Governing Council decisions on the recalibration of NIRP, FG, and APP

Date	Event	Program	Announcement
04 July 2013	GovC	FG	The Governing Council expects the key ECB interest rates to remain at present or lower levels for an extended period of time.
05 June 2014	GovC	NIRP	The rate on the deposit facility was lowered by 10 basis points to -0.10%.
04 September 2014	GovC	NIRP	The rate on the deposit facility was lowered by 10 basis points to -0.20%.
		APP	… purchase a broad portfolio of simple and transparent asset-backed securities (ABSs) under an ABS purchase programme (ABSPP)… also purchase a broad portfolio of euro-denominated covered bonds issued by MFIs domiciled in the euro area under a new covered bond purchase programme (CBPP3).
22 January 2015	GovC	APP	...launch an expanded asset purchase programme, encompassing the existing purchase programmes for asset-backed securities and covered bonds. Under this expanded programme, the combined monthly purchases of public and private sector securities will amount to €60 billion. They are intended to be carried out until end-September 2016 and will in any case be conducted until we see a sustained adjustment in the path of inflation which is consistent with our aim of achieving inflation rates below, but close to, 2% over the medium term.
03 December 2015	GovC	NIRP	...we decided to lower the interest rate on the deposit facility by 10 basis points to -0.30%.
		APP	...we decided to extend the asset purchase programme (APP). The monthly purchases of €60 billion under the APP are now intended to run until the end of March 2017, or beyond, if necessary.
10 March 2016	GovC	NIRP	The rate on the deposit facility was lowered by 10 basis points to -0.40%.
		APP	...we decided to expand the monthly purchases under our asset purchase programme from €60 billion at present to €80 billion. They are intended to run until the end of March 2017, or beyond, if necessary.
		FG	...the Governing Council expects the key ECB interest rates to remain at present or lower levels for an extended period of time, and well past the horizon of our net asset purchases.
08 December 2016	GovC	APP	...we will continue to make purchases under the asset purchase programme (APP) at the current monthly pace of €80 billion until the end of March 2017. From April 2017, our net asset purchases are intended to continue at a monthly pace of €60 billion until the end of December 2017, or beyond, if necessary
		FG	The key ECB interest rates were kept unchanged and we continue to expect them to remain at present or lower levels for an extended period of time, and well past the horizon of our net asset purchases.
26 October 2017	GovC	APP	...we will continue to make purchases under the asset purchase programme (APP) at the current monthly pace of €60 billion until the end of December 2017. From January 2018 our net asset purchases are intended to continue at a monthly pace of €30 billion until the end of September 2018, or beyond, if necessary.
		FG	...the key ECB interest rates were kept unchanged and we continue to expect them to remain at their present levels for an extended period of time, and well past the horizon of our net asset purchases.
14 June 2018	GovC	APP	...we will continue to make net purchases under the APP at the current monthly pace of €30 billion until the end of September 2018. We anticipate that, after September 2018, subject to incoming data confirming our medium-term inflation outlook, we will reduce the monthly pace of the net asset purchases to €15 billion until the end of December 2018 and then end net purchases.
		FG	...we decided to keep the key ECB interest rates unchanged and we expect them to remain at their present levels at least through the summer of 2019 and in any case for as long as necessary to ensure that the evolution of inflation remains aligned with our current expectations of a sustained adjustment path.
07 March 2019	GovC	FG	...we decided to keep the key ECB interest rates unchanged. We now expect them to remain at their present levels at least through the end of 2019, and in any case for as long as necessary to ensure the continued sustained convergence of inflation to levels that are below, but close to, 2% over the medium term.

06 June 2019	GovC	FG	...we decided to keep the key ECB interest rates unchanged. We now expect them to remain at their present levels at least through the first half of 2020, and in any case for as long as necessary to ensure the continued sustained convergence of inflation to levels that are below, but close to, 2% over the medium term.
12 September 2019	GovC	NIRP	...we decided to lower the interest rate on the deposit facility by 10 basis points to -0.50%.
		APP	...the Governing Council decided to restart net purchases under its asset purchase programme (APP) at a monthly pace of €20 billion as from 1 November. We expect them to run for as long as necessary to reinforce the accommodative impact of our policy rates, and to end shortly before we start raising the key ECB interest rates.
		FG	We now expect the key ECB interest rates to remain at their present or lower levels until we have seen the inflation outlook robustly converge to a level sufficiently close to, but below, 2% within our projection horizon, and such convergence has been consistently reflected in underlying inflation dynamics.
12 March 2020	GovC	APP	...we decided to add a temporary envelope of additional net asset purchases of €120 billion until the end of the year, ensuring a strong contribution from the private sector purchase programmes.
18 March 2020	GovC	PEPP	The Governing Council decided the following: (1) To launch a new temporary asset purchase programme of private and public sector securities to counter the serious risks to the monetary policy transmission mechanism and the outlook for the euro area posed by the outbreak and escalating diffusion of the coronavirus, COVID-19. This new Pandemic Emergency Purchase Programme (PEPP) will have an overall envelope of €750 billion. Purchases will be conducted until the end of 2020 and will include all the asset categories eligible under the existing asset purchase programme (APP).
04 June 2020	GovC	PEPP	...the Governing Council decided to increase the envelope for the pandemic emergency purchase programme (PEPP) by €600 billion to a total of €1,350 billion.

The ECB's first inroad into the perimeter of the three unconventional policies defined above was the decision to issue forward-leaning guidance on the likely future path of its policy rates in July 2013. Monetary policy at the beginning of 2013 was already operating through a *de facto* floor system. Essentially, the weekly Main Refinancing Operations (MRO), offered at a fixed rate, had lost its traditional status as the ECB's benchmark lending facility and had been transformed into a periodic backstop for banks under liquidity strains, while the rate on the deposit facility – the DFR, the corridor's floor – was setting the marginal cost of banks' borrowed reserves and thus had replaced the MRO rate as the anchor for money market overnight borrowing conditions and for the whole term structure of interest rates. While the DFR had been reduced to zero in July 2012, and the overnight interest rate had remained reasonably close to zero as a result, it had become challenging for the ECB to ensure that the shape of the term structure of interest rates consistently reflected its resolve to lock in enough accommodation in the prevailing conditions of rapid disinflation and subpar growth. Forward guidance could increase the transparency of monetary policy deliberations and plans, at a time of heightened uncertainty, by emphasising in official communication the connection between the long-run objective of monetary policy and the path of interest rates most consistent with achieving those objectives.

The early forward guidance statements were qualitative and unspecific. Nevertheless, unlike equivalent formulations adopted by other central banks, they hinted at the possibility that the policy rates could be reduced further: "*The Governing Council expects the key ECB interest rates to remain at present or lower levels for an extended period of time.*" The directional qualification in the forward guidance language ("*or lower*") disappeared in June 2014, when the ECB decided to cut the DFR to -0.1%, describing the decision as a marginal, technical adjustment to the width of the rate corridor, which arguably left little scope for further reductions. However, the DFR was reduced further to -0.2% already in September 2014 and, again, in incremental 10-basis point steps, in December 2015, March 2016 and September 2019. Explicit text carrying forward-looking indications about the likely direction of the policy rate were omitted from the post-meeting statements until March 2016.

In any event, since January 2015, an expanded Asset Purchase Programme (APP) – the ECB's version of QE – had taken up the role that is traditionally assigned to the conventional policy rate and indications of its likely direction as the primary instruments of monetary policy. This rotation from policy rates to asset purchases in messaging about the monetary policy stance was based on two considerations: the ECB judged that policy rates were already close to their lower bound and, in the highly fragmented financial landscape of the time, QE was indeed viewed as the instrument that could impart the maximum amount of stimulus in the largest number of member economies. Therefore, when the ECB announced in late January 2015 that it would purchase public and privately-issued securities at a monthly rate of €60 billion under APP, FG mainly referred to the size and duration of APP. During the three-year period that ensued, the formal policy statement governing the FG on purchases was based on a dual key approach: it gave time-based guidance, referring to a calendar date to indicate the horizon over which the public could expect the monthly purchases to run; and it gave state-contingent guidance by indicating that, in any event, purchases would continue even beyond that calendar date, until the Governing Council of the ECB was sufficiently confident that projected inflation was on a path toward its policy aim of "*below but close to 2%*". A "*sustained adjustment in the path of inflation*" was the economic outcome invoked as a condition for ending the programme. The specification of a euro billion amount to be raised per month was meant to telegraph a steady presence in the secondary market, and to reassure those market participants wedded to the *flow view* of central bank purchases – which maintains that QE is effective to the extent that it bolsters the demand for bonds per unit of time – that the ECB would be a source of demand for an extended period of time. The time horizon for the programme, instead, was meant to facilitate the calculus of those analysts who thought of QE in terms of the *stock view*: what matters for financial prices and the economy is the eventual increase in the size of the central bank's bond holdings, not the pace at which the central bank adds to its portfolio. The size and duration of the QE programme was subsequently recalibrated in December 2015, March 2016, December 2016, October 2017 and finally June 2018, when the ECB signalled that the programme was being phased out through the end of the year. Cumulatively, as a result of the QE programme, the ECB's holdings of bonds rose by around €2.6 trillion between January 2015 announcement and the end of 2018. In line with this FG architecture, at each recalibration –with the exception of March 2016, when the monthly pace was upsized – the Governing Council updated the date-based element of the APP forward guidance, extending the minimum horizon for the monthly purchases, while always keeping its intentional horizon linked to the inflation objective (through the *sustained adjustment* conditionality).

In 2016, rate FG was revived, although as a derivative of the guidance on QE. Rate FG had remained dormant for a long while, as the Governing Council's indications on the likeliest outlook for APP size and duration had taken centre stage as the principal channel for telegraphing the stance. In the January 2016 policy statement, however, the original phrase that the key ECB interest rates were expected "*to remain at their present or lower levels for an extended period of time*" was resumed as part of a broader signalling tactic to prime the markets for an imminent rate action. And indeed, in the March post-meeting statement, while the DFR was cut to -0.4%, the rate guidance was "chained to" the principal formulation, still pertaining to the duration and size of the APP. The Governing Council said that it expected the key ECB interest rates "*to remain at present or lower levels for an extended period of time, and well past the horizon of our net asset purchases.*" This indication fell short of providing the private sector with much specificity about either the likely date of liftoff of the policy rates or the economic conditions that would trigger it. But, the sequrencing relative to the calendar-part of the APP horizon at least was a signal that the horizon to a rate increase was considerably longer than the horizon to the end of the asset purchases. Finally, in June 2018, as the ECB signalled termination for its QE programme by year-end, FG on the policy rates regained its traditional precedence in the hierarchy of the policy tools. The post-June 2018 FG inherited the characteristic dual-key conditionality that had been applied since 2015 when signalling the APP's duration: a calendar time to indicate the nearest date for a lift-off, and a "*sustained adjustment*" condition invoking an inflation outcome to justify a start of rate normalisation. In June 2018, the statement included explicit reference to a time horizon, saying that the Governing Council expected the ECB's key interest rates (the corridor) *"to remain at their present levels at least through the summer of 2019 and in any case for as long as necessary to ensure that the evolution of inflation remains aligned with our current expectations of a sustained adjustment path."* As it turned out, such date-based guidance prompted dovish revisions in the public's expectations regarding the timing of lift-off and possibly the longer-run conduct of monetary policy more generally, and thus helped the ECB navigate the difficult juncture of having to communicate the end of a pivotal programme such as APP, in conditions in which the economy was judged to need a still substantial amount of monetary accommodation. The cited time horizon was extended twice to later dates in March and June 2019.

Against a backdrop of faltering growth and persistently weak inflation pressures, the September 2019 Governing Council meeting saw the resumption of APP (at a monthly pace of €20 billion, to be terminated "*shortly before*" the ECB starts raising its key interest rates), a further reduction of the DFR to -0.5%, and a new formulation for the rate guidance, now entirely based on economic outcomes. The Governing Council stated: "*we expect the key ECB interest rates to remain at their present or lower levels until we have seen the inflation outlook robustly converge to a level sufficiently close to, but below, 2% within our projection horizon, and such convergence has been consistently reflected in underlying inflation dynamics.*" In other words, a rate hike would not be justified if inflation was foreseen to approach the policy aim only at the very end of the projection horizon. Instead, the ECB would await confirmation that inflation was indeed on track to a robust, irreversible convergence by seeking an early convergence of future inflation within the projection horizon, and by looking at contemporary measures of underlying price pressure. Following the resumption of net purchases under APP, the stock of bonds acquired rose to almost €2.8 trillion by mid-2020.

The new Pandemic Emergency Purchase Programme (PEPP), unveiled in the night of 18 March 2020 in response to the financial and macroeconomic fallout from the Covid-19 pandemic, conflated two elements: a market functioning, backstop-type intervention modality, on one hand, and a stance-supporting mission founded on duration extraction, on the other. While the former element was tailored to stemming the market panic that was unfolding at the time in which the programme was launched, the second element became more salient when markets eventually calmed, and the clouds shrouding the macroeconomic outlook started to dissipate. As the economic damage wrought by the shock became clearer, the ECB resized the programme in June with a view to bridging the economy over the on-going deep contraction and re-anchoring medium-term inflation.

3. Event study analysis

We follow a burgeoning stream of research in trying to identify the impact of FG and QE innovations on asset prices through an event study methodology. The empirical model we use for identifying innovations to the two instruments has the following general specification:

$$\Delta \mathrm{x_t} = \sum_{j=1}^{k} \lambda_j D_{j,t} + \sum_{j=1}^{k} \vartheta_j D_{j,t-1} + \alpha \Delta E_t^Y + \beta \Delta E_t^P + \gamma \Delta E_t^{QE} + \phi News_t^{EA} + \omega News_t^{US} + \zeta \Delta CISS_t + \rho \Delta i_t^{3m} + \mu \Delta f_t^{3m-in-18m} + \epsilon_t, \quad (1)$$

where Δx_t stands for different variables, depending on whether we score the impact of QE or FG. When estimating the impact of QE, $\Delta x_t = \Delta i_\mathrm{t}^\tau$ where Δi_t^τ is the daily change in the euro area sovereign bond yields[15] with maturity (measured in years) τ, and $\tau = 1, \dots 10$; $D_{\mathrm{j,t}}$ is a vector of event dummies (listed in Table 2) that assume value one in the event days and zero elsewhere; $\Delta E_\mathrm{t}^\mathrm{Y}$ and $\Delta E_\mathrm{t}^\mathrm{P}$ stand for the ECB staff forecast revisions for GDP growth and HICP inflation, respectively. We compute the revisions as the difference between the end-of-horizon (typically two years ahead) projected value of annual GDP growth and inflation between two consecutive staff projection vintages. As staff projections

[15] The euro area sovereign yields are obtained by aggregating individual bonds with similar maturity from all euro area countries using the modified Nelson and Siegel (1987) method developed by Svensson (1994). This methodology does not aggregate national sovereign bonds into euro area sovereigns directly using weights (based for example on national GDP levels). Indirectly, however, one could claim there is some weighting as the synthetic euro area government bonds obtained with the Svensson methodology reflect at each point in time the number of available bonds in the market from all euro area countries. As larger countries tend to have a higher volume of bonds outstanding in the market, sovereign bond markets from larger countries receive a higher weight than those countries with a smaller number of government securities. At the same time, our bond aggregate assigns larger implicit weights to high-debt countries, such as Italy, relative to low-debt countries such as Germany. See Nymand Andersen (2018) for details.

are produced at quarterly frequency, we set to zero all values except for the days corresponding to a Governing Council meeting in which staff submits the projections. Finally, in Equation (1) $\Delta E_{\mathrm{t}}^{\mathrm{QE}}$ indicates the market expectations of a QE (re)calibration; $News_{\mathrm{t}}^{\mathrm{EA}}$ and $News_{\mathrm{t}}^{\mathrm{US}}$ are macroeconomic surprise indicators constructed by Citi Group and available in Bloomberg for the euro area and the US, respectively; *CISS* is the Composite Indicator of Systemic Stress proxying for uncertainty; $i_{\mathrm{t}}^{3\mathrm{m}}$ is the 3-month OIS spot rate and $f_{\mathrm{t}}^{3\mathrm{m-in-18m}}$ is the 3-month OIS forward rate in 18-month.

When assessing the impact of FG, $\Delta x_{\mathrm{t}} = \Delta f_{\mathrm{p,t}}^{\tau}$ where $\Delta f_{\mathrm{p,t}}^{\tau}$ is the daily change in the *p*-th percentile (with $p = 0.15, 0.25, 0.35, 0.45, 0.5, 0.55, 0.65, 0.75, 0.85$) of the option-derived predictive distributions for the future short-term rate (see Section 4) τ months ahead, with $\tau = [9, 12, 18]$. The set of explanatory variables used for the analysis of FG is the same as for the QE analysis, except for the time dummies ($D_{\mathrm{j,t}}$), which reflect a different event set (see below and Table 2), and the restriction that the coefficients μ and γ be set to zero. As we explain below, $D_{j,t}$ refers to QE-relevant events when the variable on the left of the equation is Δi_t , and to FG-relevant events when the variable on the left is Δf_t .

Typically, in event study analyses the econometrician registers high-frequency changes in selected financial variables, such as yields of different terms, over short windows of time around a selection of monetary policy announcements, and considers these movements as clean measures of monetary policy surprises. We depart from the conventional practice of event analysis in several ways. First, we expand the grid of the policy-relevant events (the event dummies, $D_{j,t}$) to include not only post-meeting monetary policy announcements, but also a small selection of high-level speeches by the ECB's President, the date (March 9 2015) on which the ECB started actual purchases in the secondary market, and the so-called Bund Tantrum episode in late April 2015 (see below). In addition, our grid includes a handful of binary events that prove to have moved interest rates perceptibly. These correspond to communications unrelated to monetary policy narrowly defined (two Governing Council decisions taken in April 2020 concerning the eligibility criteria for collateral acceptable in the ECB lending operations, and the Franco-German agreement on what would become the Next-Generation EU plan in May 2020), and the post-Brexit referendum reaction in financial markets on June 24 2016. The binary non-policy events are used as controls but do not enter the accounting of impacts for QE or FG. In selecting the events related to the ECB's monetary policy, we concentrate on those post-meeting statements and presidential speeches which demonstrably were intended to convey news about the (re)calibration of either FG, or QE, or both, or message the ECB's orientation to recalibrate the three instruments in the near future. This selection is designed to act as a filter to retain the deliberate, *Odyssean* policy signal of the ECB's communication and minimise the noise that would be injected into the universe of our observations if we had included indiscriminately all the post-meeting communications, even those in which there was no discussion about disclosing a message related to the monetary policy stance. While our approach does not filter out episodes in which unscripted utterances in the post-meeting Question/Answer sessions produced unintended market impacts, it does minimise the frequency of those occurrences in our sample to the extent that the communication after meetings that unveiled policy decisions might have been crafted to telegraph a clean policy message. ΔE_t^Y and ΔE_t^P, the surprise components entailed in the quarterly publications of the ECB staff projections, are two additional filters that we use to distil the pure *Odyssean* message from any *Delphic* disclosure of information on the ECB's general macroeconomic assessment.[16]

Table 2 shows the list of our events. The first two columns from left tabulate the date of the event and classify the event as a post-Governing Council meeting announcement, as a presidential speech, as a monetary policy action strictly related to one of the instruments considered, or as one of the non-monetary policy shocks that we consider. The third and fourth columns separate the events according to whether they carried relevant information concerning QE or FG. Since for more than two years the ECB's rate FG was chained to the guidance on the duration of the QE programme (see Section 2), many events are classified as carrying relevant information for both QE and FG. We discuss the results reported on the four rightmost columns of Table 2 in Section 3.

In order to validate our selection of events and assignment of events to instruments, we compare this "narrative approach" in dating monetary policy shocks with a more agnostic approach based on an index of intensity of news coverage. We use two indexes of news coverage, one pertaining to QE and one to rate FG. Both indices are derived from an extensive range of different news sources available in the Dow Jones news database, Factiva. For each calendar day, we search for a number of keyword variables related to the announcement and the implementation of the ECB's APP and FG, respectively, and select articles on the basis of such key words and exclusion criteria.[17] We plot the intensity indicators pertaining to APP and FG, respectively, in Figure 4. It is striking to note how the news indexes have a tendency to spike

[16] A number of studies have documented the importance of the information disclosure effect in central bank communication. See, for example, Miranda-Agrippino and Ricco, 2020; Altavilla *et al.* 2019; Jarociński and Karadi, 2020.

[17] Specifically, for the APP Index, the query is set in such a way that for an article to be included in our sample it should simultaneously contain at least one word coming from two different sets. The first set is "ECB", "European Central Bank", "Draghi" and, from 2020, "Lagarde". The second set is "QE", "quantitative easing", "asset purchase", and "APP". To avoid possible contamination of the results from QE programs of other central banks we exclude the article if it contains one of the following words: "Federal Reserve", "Bank of Japan", "Bank of England", "BoJ", "BoE", "Fed", "Japan", "US", "U.S.", and "England". We limited the search to English-language news sources with subject "Euro Zone/Currency" as attributed by Factiva. The FG Index is derived following the same approach. The first set of words comprises "ECB", "European Central Bank", "Draghi" and, from 2020, "Lagarde". The second set includes "forward guidance" or "as long as necessary" or "lower levels until" or "extended period of time" or "well past" or "at least through". At the same time we shall not have in the same paragraph "Federal Reserve" or "Bank of Japan" or "Bank of England" or "BoJ" or "BoE" or "Fed" or "Japan" or "US" or "U.S." or "England" or "Britain" or "Riksbank" or "negative rates".

around the identified event dates, reaching clear local maxima concomitantly with Governing Council meetings.

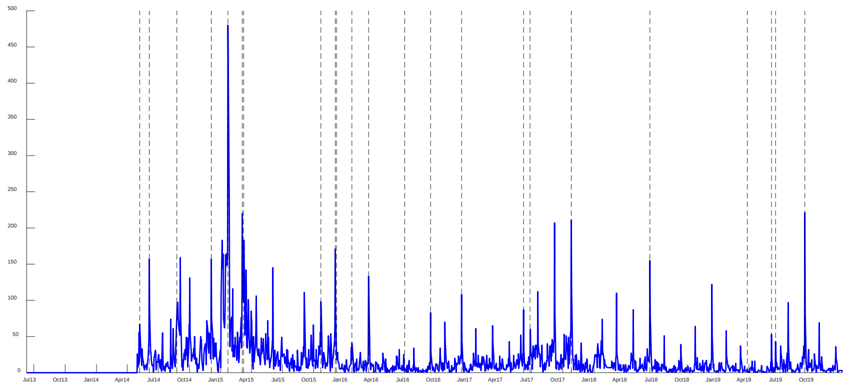
Table 2: List of ECB monetary policy events associated to APP, FG, or both

Date	Description	QE	FG	10-year		3M-in-18M	
				Classical	Controlled	Classical	Controlled
04/07/2013	Governing Council meeting	-	Yes	-4.9***	-1.6*	-7***	-7.4***
07/11/2013	Governing Council meeting	-	Yes	1.2**	3.6*	-3**	-8.1***
09/01/2014	Governing Council meeting	-	Yes	2.1	4.7*	-3*	-8.7***
08/05/2014	Governing Council meeting	Yes	Yes	-5.3**	-3.9*	-4**	-3.2***
05/06/2014	Governing Council meeting	Yes	-	-16.2**	-13.7***	-5*	8.1***
25/08/2014	Draghi speech, Jackson Hole	Yes	-	-9.6**	-8.8**	-3**	-1.6***
04/09/2014	Governing Council meeting	Yes	-	-12.5*	-11.0**	-5***	-6.3*
04/12/2014	Governing Council meeting	Yes	-	-1.3	-1.1*	1	6.4*
22/01/2015	Governing Council meeting	Yes	-	-13.8*	-13.4***	-3	-3.6**
05/03/2015	Governing Council meeting	Yes	-	-6.2**	-12.5*	0	-4.3***
09/03/2015	First day asset purchases	Yes	-	-14.1*	-12.5***	-2	-3.9***
29/04/2015	Bund Tantrum	Yes	-	18.4***	15.4***	6	6.9**
03/06/2015	Governing Council meeting	Yes	-	12.4**	13.9***	1	4.3**
22/10/2015	Governing Council meeting	Yes	Yes	-9.1***	-6.9**	-7**	-4.9***
03/12/2015	Governing Council meeting	Yes	-	21.2***	11.7***	12**	15.4***
07/12/2015	Draghi speech, New York	Yes	-	-10.6**	-10.3**	-1	-3.8
21/01/2016	Governing Council meeting	Yes	-	-2.2**	0.9	-3**	-4.6***
10/03/2016	Governing Council meeting	Yes	-	-2.6**	-5.9*	3***	7.4***
24/06/2016	Post Brexit referendum	-	-	-8.4**	-8.3***	-5**	-4.1***
08/09/2016	Governing Council meeting	Yes	-	14.0**	14.6***	3	2.5*
08/12/2016	Governing Council meeting	Yes	Yes	5.0*	4.3*	-1	-0.2*
08/06/2017	Governing Council meeting	Yes	Yes	-11.9*	-14.2**	-3	-0.7*
27/06/2017	Draghi speech, Sintra	Yes	Yes	11.6***	10.4***	5*	3.1**
26/10/2017	Governing Council meeting	Yes	Yes	-6.2**	-5.1*	3*	-3.8***
14/06/2018	Governing Council meeting	Yes	Yes	-9.9***	-9.0**	-9*	-4.7***
07/03/2019	Governing Council meeting	-	Yes	-13.5**	-10.9***	-3*	-5.2***
27/03/2019	Draghi speech, Watchers conf.	Yes	-	-3.3**	-1.2	-2*	-5.8***
06/06/2019	Governing Council meeting	Yes	Yes	-9.2*	-6.5*	1	-2.5**
18/06/2019	Draghi speech, Sintra	Yes	-	-8.5***	-6.1**	-11*	-4.1**
12/09/2019	Governing Council meeting	Yes	Yes	3.0**	-1.2*	7**	7.9***
12/03/2020	Governing Council meeting	Yes	-	25.0***	16.0***	10***	11.5***
19/03/2020	PEPP announc. (18/03, 23:00)	Yes	-	-25.0***	-19.9***	7**	-0.9*
26/03/2020	PEPP legal act	Yes	-	-23.0***	-17.7***	-8**	-7.0*
07/04/2020	Collateral	-	-	11.0**	10.9**	4	2.8*
23/04/2020	Collateral	-	-	-12.0*	-1.5	-8	-2.3**
18/05/2020	Franco-German agreement	-	-	-2.6	-2.8*	3	2.3**
04/06/2020	PEPP recalibration	Yes	-	0.3	-0.6	2	-1.5**

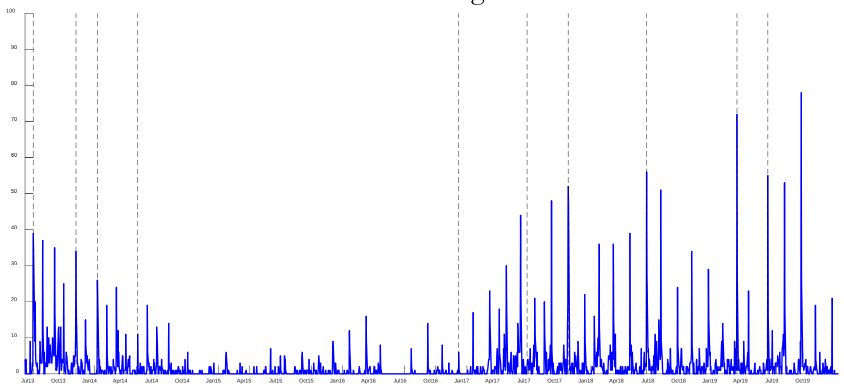
Notes: The table reports the set of event dates used in the empirical analysis for both quantitative easing (third column) and forward guidance (fourth column). The table also report the 2-day event study result (both classical and controlled) for the 10-year sovereign bond yield, and the median 3-month forward of the option-derived predictive distributions for the future short-term rate in 18 months. Results for "classical" event study are derived by estimating a regression where the dependent variable is regressed solely on a set of event dummies. Results for "controlled" event study are obtained from a regression where the dependent variable is regressed on a set of event dummies and the additional controls as reported in equation 1.

Figure 4: Index of news on ECB's asset purchases and rate forward guidance *(index)*

News on asset purchases



News on forward guidance



Source: Factiva.

Second, we take into account that financial prices might adjust to monetary policy announcements non-instantaneously. This is particularly true when the announcements describe complex packages of measures whose financial implications are worked out in the marketplace only through a reflective and learning process. Repeated observations of price dynamics following an announcement of unconventional measures lead us to conclude that convergence to a market "view" about the implications of the measures typically appears to take no less than 2 days, so the amplitude of our time window defining an event is 2 days.[18] This requires that we control for non-monetary policy sources of information that might intervene within the 2-day window to simultaneously move market conditions. Hence the two macroeconomic

[18] Using a 2-day event window is quite common in the literature of non-standard measures. See, for example, Krishnamurthy and Vissing-Jorgensen. (2011), Swanson (2011), Bowman *et al.* (2015)) as well as MacKinlay (1997) for an application to finance. Jones, Lamont, and Lumsdaine (1998) and Fleming and Remolona (1999) provide supporting evidence for this choice. In results available from the authors upon request, we show that the difference in the estimated cumulative impacts of FG and QE on the forward rate and on the 10-year yields, respectively, obtained from our 2-day event window methodology – as shown in Figures 8.2 and 8.3, respectively – and from an alternative methodology using a 1-day event window is negligible by the end of the sample.

surprise indicators, $News_{\mathrm{t}}^{\mathrm{EA}}$ and $News_{\mathrm{t}}^{\mathrm{US}}$, on the right-hand side of equation (1). For both, we use the Citi macroeconomic surprise index.[19]

Third, importantly, we allow for the building of expectations of future policy action. We construct a new measure of changes in the medium-term portfolio of bonds acquired under QE (ΔE_t^{QE}) that investors, at each point in time, were anticipating the ECB would announce at the next (re)calibration of its asset purchase programme. To infer the private-sector anticipations concerning the ECB's sequential recalibrations of its asset purchase programme we use Bloomberg survey data over the first part of our sample extending to March 2019. Starting from April 2019, we rely on the information extracted from the ECB Survey of Monetary Analysts (SMA). Surveys have been querying panellists, with increasing precision and accuracy, about their expectations of ECB's balance sheet policies since September 2014.[20] From these responses, we first extract a measure of QE expectations – in terms of median across survey respondents – at the frequency of the Governing Council policy meeting. We then derive a corresponding daily-frequency proxy for QE expectations, via a temporal disaggregation technique informed by the pattern of the daily-frequency indicator represented by Factiva index on ECB's asset purchases.[21]

Figure 5 plots the events as vertical markers against the time evolution of the 10-year average sovereign bond yield, the 3-month spot OIS rate, the 3-month in 12 months forward OIS rate and our measure of expectations of the ECB's QE bond portfolio.

Finally, we want to purge our measure of monetary policy surprises from the noise that might otherwise muddle identification in episodes of excess financial volatility, so we add $CISS_t$ to the number of regressors to control for stress in the marketplace.[22] In addition, we orthogonalize the observed changes in the medium- to long-end portion of the sovereign yield curve (the upper percentiles of the options-

[19] The Citi Economic Surprise Index (CESI) summarise the difference between actual macroeconomic data releases and professional forecasters expectations of the same data. The index is computed by Citigroup at a daily frequency, since 2003, and it is based on weighted, standardised data surprises combing both hard and soft information. Surprises are defined as the actual release minus the median of professional forecasters surveyed by Bloomberg. A positive value of the index suggests that data releases were generally above market expectations.

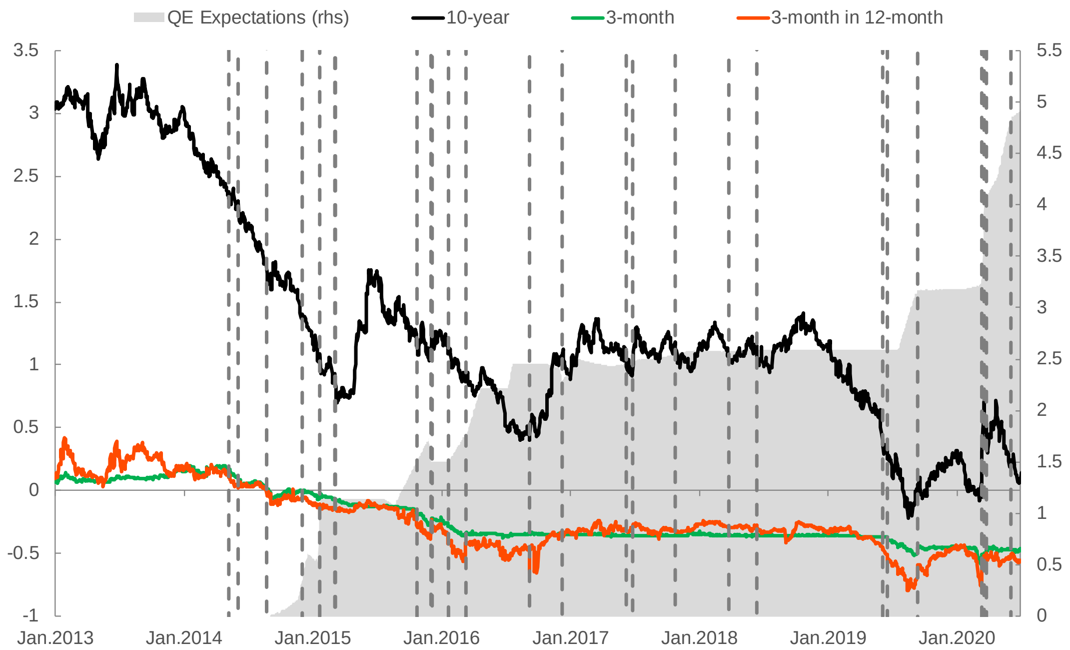
[20] For instance, in the Bloomberg surveys from September 2014 until December 2014, we extract QE expectations indirectly, combining reported information on the probability of a launch of a government QE with the expected size of QE, conditional on that announcement. Specifically, the probability of a launch of a government QE is proxied by the number of respondents expecting a government QE out of the total survey respondents. The expected size of QE is derived as the difference between the reported changes in ECB balance sheet foreseen by respondents over the subsequent years, net of their expectations about TLTROs uptake.

[21] Specifically, we use Chow-Lin method as a temporal disaggregation technique to derive high frequency data from low frequency data on QE expectations. This method also uses indicators on the high frequency data, which contain the short-term dynamics of the target time series. In our application, as an indicator, we use Factiva index on ECB's asset purchases. Intuitively, this index serves the purpose of informing the daily pattern for the temporal disaggregation of the lower frequency series of QE expectations.

[22] The Composite Indicator of Systemic Stress (CISS) aggregates 15 individual financial stress measures to measures the level of stress in the financial system (see Holló et al. 2012). The index is publicly available online from the ECB's Statistical Data Warehouse (SDW).

derived predictive density) with respect to shifts in the very short end of the money market, which is most sensitive to NIRP news – by adding the 3-month spot OIS rate, i_t^{3m} – or moves in the forward curve at an 18-month maturity, which is most sensitive to FG – by adding the 3-month in 18-month forward rate.

Figure 5: Short-term rates, long-term yields, and survey-based expectation of ECB's asset purchases *(lhs: percentages per annum; rhs: €tn)*



Notes: Survey-based expectations are derived using information on APP and PEPP purchases extracted from the Bloomberg and the Survey of Monetary Analysts (SMA) survey. Latest observation: 30 June 2020.

In Table 3 we selectively report the results of the event study for the 10-year yield and a representative percentile (the median) of the predictive option-based rate distributions that we use as left-hand variable in regression (1) when gauging the quantitative impact of FG on forward rates. For convenience, we separate the tabulation of our econometric results between Table 2 and Table 3, with the former reporting the estimates of the coefficients attached to the event dummies and the latter reporting the coefficients attached to the non-event controls. Figure 6 shows the structure of impacts of the FG events across various percentiles of the option-derived predictive densities. A few results are worth singling out. First, the selected monetary-policy events, with only few exceptions, prove to be highly significant explanatory variables of the daily historical variation in interest rates. These are the events marked with a "Yes" in Table 2. Note that, among such events, we include episodes in which the release of the policy decision was met with market disappointment and the intended easing effect of the measure was partly reversed upon announcement. Three such QE-relevant episodes stand out: the communication of the decisions to extend the horizon of asset purchases by six months – but only taking effect nine months out – in December 2015; the ECB President's speech delivered at the ECB's annual symposium in Sintra on June 27 2017, when market participants interpreted the upbeat description of the economic outlook as signalling an imminent firming of policy; and the reaction to the March 12 2020 Governing Council decisions. While the December 2015 episode only caused a partial reversion of the sustained decline in yields that had been driven by anticipations of a strong monetary policy package prior to the Governing Council's meeting, and the March 12 2020 surge in yields was quickly, if only partially, reabsorbed by the subsequent announcement of the PEPP programme, the late-June 2017 event detracted from the overall QE effects on net. There is also evidence of perverse market reactions to intentionally easing FG announcements. One such occurrence is the switch to a fully state-contingent formulation for rate guidance in September 2019, although the September 2019 episode shares characteristics of both a NIRP action disappointment and a tightening FG surprise (the green dot in the North-East quadrant of Figure 1.2 indeed corresponds to the September 2019 announcement).[23]

Second, accounting for expectations about the future evolution of the ECB's balance sheet is important in explaining the daily evolution of the sovereign yields: the coefficient attached to $\Delta E_{\mathrm{t}}^{\mathrm{QE}}$ in Table 3 is large and significant. Third, Table 3 shows that the controls related to macroeconomic surprises are generally statistically insignificant, except for the impact of US macroeconomic news on the forward curve, the CISS indicator of market turbulence and, somewhat surprisingly, inflation projections surprises on both the 10-year bond yield and the forward curve. Surprise revisions in the ECB's growth projections have been significant drivers of shifts in the 10-year interest rate and, more strongly, the forward rate for the entire history considered. Indeed, as a test for the stability of the regression coefficients, we also conduct recursive estimations. Starting from a sample that includes the beginning of 2013 through the date of the APP announcement (January 22 2015), we add one data point at a time through the end of the sample utilised for estimating the model (December 31 2019), and we re-estimate the model recursively. As shown in Figure 7, the recursive estimates of the event study parameters do not show material instability over the period considered.

Last, Figure 6 shows that the impacts from all of the FG-related events were highest for the upper percentiles of the contemporary rate predictive densities. We consider the result as lending support to our identification strategy concerning innovations to the FG policy on different segments of the distributions.

[23] Markets had approached the September 2019 post-meeting announcement pricing in a full 20bp reduction in the DFR. As it turned out, the ECB cut the DFR by only 10bp and announced a new two-tier system for reserve remuneration whereby a multiple of the banks' required reserves would be exempt from the negative-DFR fee. The latter decision was interpreted by some market analysts as having the potential for exempting such a large share of excess liquidity as to weakening the impact of the new DFR level (-0.5%) on the overnight money market rate.

Table 3: Event study regression

	10-year	3M-in-18M
i_t^{3m}	31.734***	54.217***
	(11.732)	(8.110)
$f_t^{3m-in-18m}$	28.822***	
	(3.536)	
$CISS_t$	0.766	9.764
	(9.887)	(6.896)
$News_t^{US}$	0.0327**	0.0147
	(0.0195)	(0.0136)
$News_t^{EA}$	0.058***	0.045***
	(0.0175)	(0.0122)
ΔE_t^{QE}	-0.0266**	
	(0.0134)	
$\Delta\, E_t^{Y}$	59.231*	65.329***
	(32.548)	(22.685)
$\Delta\, E_t^{P}$	6.995	9.238
	(19.500)	(13.579)
N. observations	1,712	1,712
R-squared	0.23	0.17

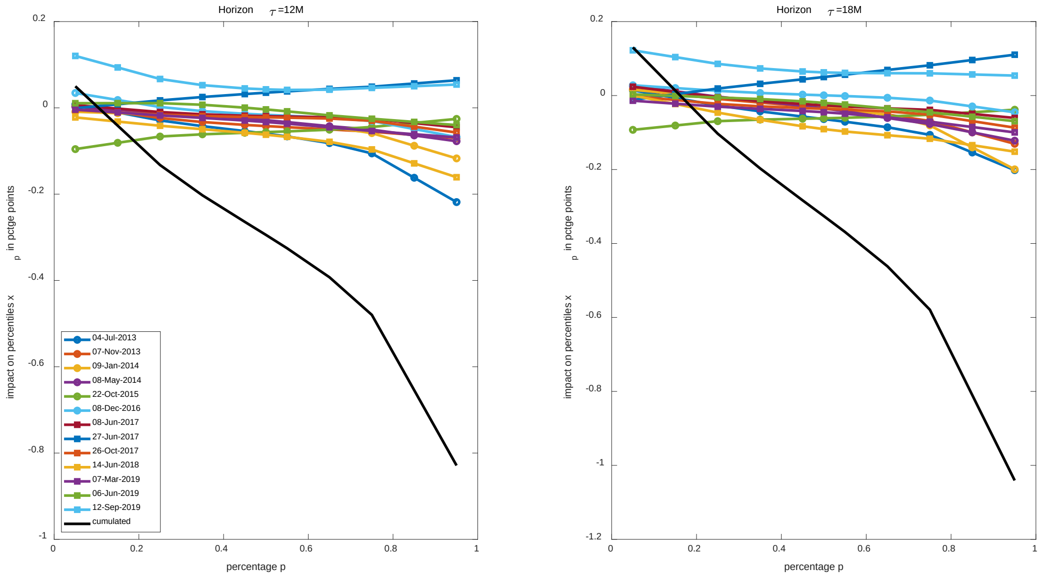
*Note: the table reports the estimation results for the coefficients included in the event-study regression for the 10-year sovereign yield (second column) and the median 3-month forward of the option-derived predictive distributions for the future short-term rate in 18 months. Results are reported in basis points. Data are daily and the sample goes from January 2013 until the end of December 2019. The symbols ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively.*

Table 4: ECB's recalibration of asset purchase programmes and estimated impact on 10-year sovereign yields (impacts of announcement and prior expectations)

Date of the recalibration	Size of the recalibration (in bn)	Estimated impact on 10-year yields (in bps)	Elasticity of yields per € 100 bn (in bps)
22/01/2015	1140	-93	-8.1
03/12/2015	360	-5	-1.5
10/03/2016	240	-14	-5.8
08/12/2016	540	-7	-1.3
26/10/2017*	315	-19	-6.1
12/09/2019	580	-33	-5.7
12/03/2020**	120	15	12.2
18/03/2020**	750	-28	-3.8
04/06/2020	600	-36	-6.0

*Note: *The size of the recalibration associated to the 26 October 2017 comprises the €270bn announced at that Governing Council meeting, as well as the tapering envelope amounting to € 45bn that was formally communicated at the June 2018 Governing Council meeting. ** The estimation of the yield impact associated to the two March 2020 Governing Council meetings is subject to particularly high uncertainty; this is due to high market volatility around those episodes and considering that the regression methodology rests on the revisions in market expectations about the overall stock of asset purchases and these revisions are hardly identified around those recalibration episodes.*

Figure 6: Impact of FG on the percentiles of the 3month-in-12months and the 3-month-in-18months predictive density

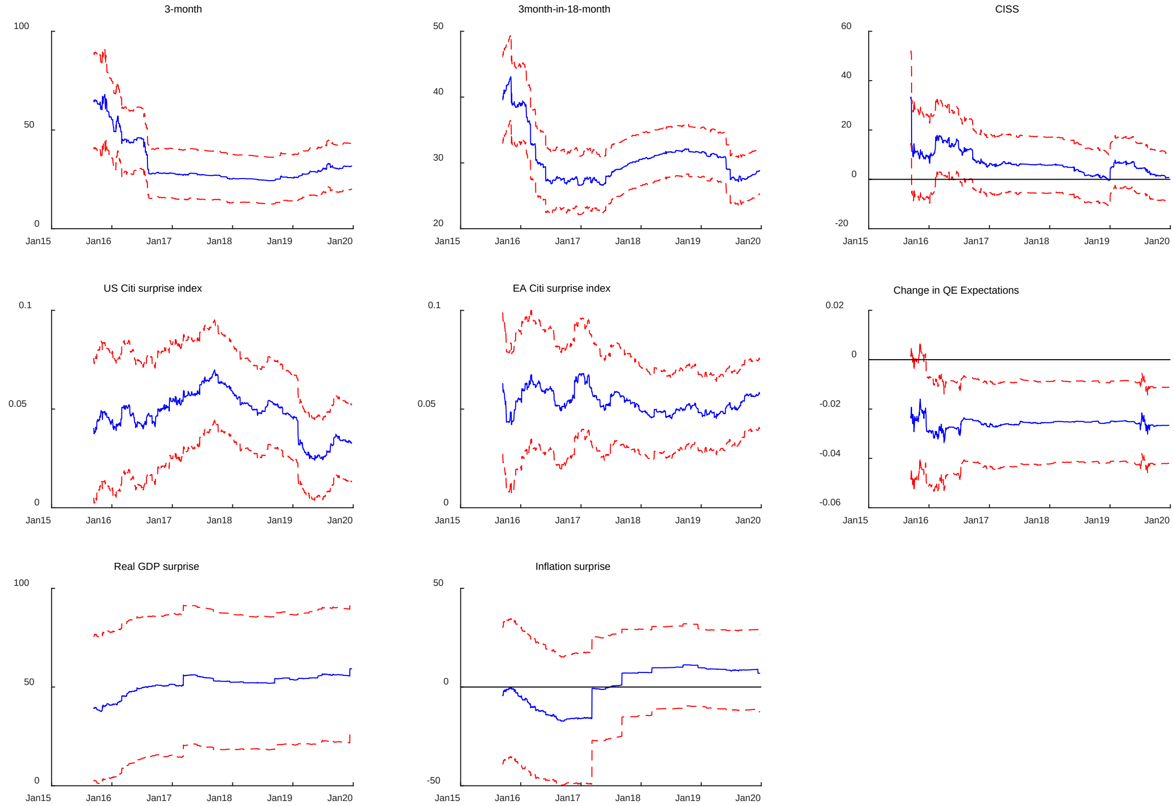


Notes: Estimated two-day impact of FG events on percentiles of 3M-in- τM predictive densities: sum of estimated λ and ϑ in equation (1) for the respective event, and the respective horizon τ (12M, LHS, and 18M, RHS). Black line cumulates across the 13 events.

4. Rate counterfactuals

In order to score the overall effects of QE on the history of sovereign yields in the euro area, we sum up the estimated coefficients attached to the QE-type events and the time-varying expectational effects that we identify through our measure of the QE bond holdings expectations. Table 4 reports the overall estimated sensitivities of the 10-year yield to subsequent rounds of QE recalibrations, summing up the responsiveness upon announcement (the coefficients attached to the event dummies reported in the right-most column of Table 2) and the prior build-up of investors' anticipations. The third and fourth columns from left document the impacts of each recalibration, expressed in unadjusted terms and adjusted by the size of the announced rescaling of the programme, respectively. Figure 8.3 shows the cumulative estimated effects of QE on the 2-year, 5-year and 10-year sovereign yields. As shown in the picture, the programme appears to have eased financial conditions appreciably relative to what they otherwise would have been. Concentrating on the time profile described by the blue line in Figure 8.3, the various rounds of reconfigurations of the ECB's asset purchases – whether under APP or PEPP – have produced a cumulative effect on the 10-year sovereign yield that, by end-June 2020, we estimate at around 200bp, of which 90bp are due to expectations formed before the announcements and 110bp due to market surprises following the announcements (adding to or subtracting from the overall easing impact).

Figure 7: Recursive estimation of the event-study coefficients



Note: The chart reports the recursive estimates of the event-study regression coefficients. Starting from a sample that goes from January 2013 until the date of the APP announcement (22 January 2015), we add one data point (i.e. one day) at a time through the end of the sample (31 December 2019). At each iteration the impact coefficients are re-estimated and stored.

We recognise four phases in the history of the programme. The first phase runs roughly from summer 2014 through late April 2015, and corresponds to the precipitous fall in long-term rates fostered by growing expectations of an imminent QE announcement (see the grey area in Figure 5), and the further downward adjustments that occurred on the day in which APP was announced and on the day in which the ECB eventually started purchasing in the secondary market. In late April 2015, the 10-year yield snapped back sharply, and the correction continued for more than two months. The trigger for the abrupt change in direction in the 10-year yield was a minor upside surprise in the German year-on-year inflation outturn on April 29, but the sustained and protracted nature of the adjustment over the weeks following the inflation news reveals the presence of an underlying market dynamic working as an amplifying force. As we explain in Rostagno *et al.* (2019), indeed the sell-off in the euro area bond market was strengthened and made more protracted in time by the way the purchasing pattern under APP varied in response to market yields. Due to the stipulation that the ECB could not purchase securities whose yield to maturity fell below the DFR, duration extraction under the programme was self-reinforcing, with the average maturity of the purchased bonds becoming longer as market yields declined, thus amplifying market changes. Two months of sharp declines in bond yields since the ECB had started buying bonds in early March had made the shorter end of the curve ineligible under the ECB's programme and driven purchases to target longer and longer-dated securities, which had added further downward pressure on market yields. As short-term yields surged at end-April, however, purchases turned to shorter-maturity securities, which once more amplified the market movement, now in the opposite direction. While our event study specification fails to account for the market mechanism explaining the prior accelerated decline in yields, we do consider the sharp reversion of April 29 as being a manifestation of design features inherent in the programme. Accordingly, we subtract the yield snap-back observed on that day – and the following one – from our overall estimate of the yield effects of QE.

The second phase of a QE-induced decline in market yields started in late 2015, when market analysts began to ramp up their QE expectations. Though punctuated by occasional short-lived market reversals, that phase plateaued only in late 2016, when the ECB commenced signalling a gradual re-normalisation of the run-rate of purchases. The third phase of sustained decline in long-term yields developed in the course of 2019, as media reports and market analysts caught on with the rapidly deteriorating economy and began to foreshadow a renewed round of net purchases: see the steep increase in the grey area around mid-2019 in Figure 5. Finally, as the pandemic shock hit in early 2020 and PEPP was announced on March 18, the new aggressive round of bond purchases led to a further steep fall in the 10-year yield by 50bp by mid-year.

Figure 8: "*No*-NIRP *with* FG", "*No*-NIRP / no-FG", and *no*-QE

Figure 8.1: Cumulated changes in actual DFR and Eonia, and cumulated effect of NIRP on the 3m-in-18m OIS *(percentage points)*

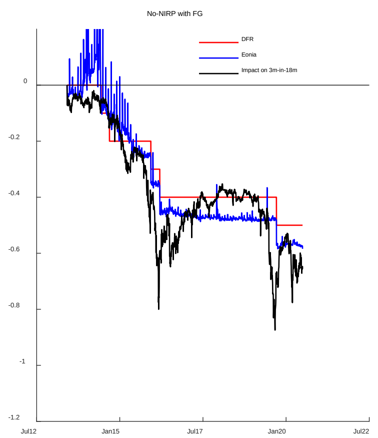


Figure 8.2: Cumulated changes in actual DFR and Eonia, and cumulated effect of NIRP and FG on the 3m-in-18m OIS *(percentage points)*

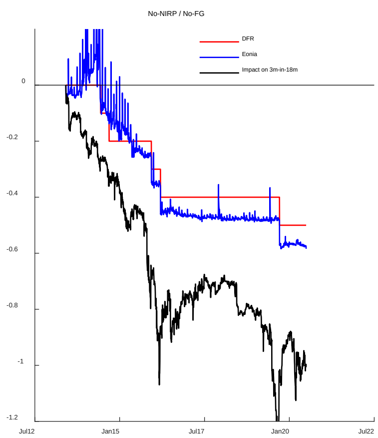
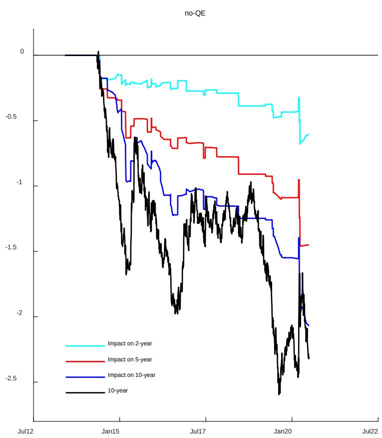


Figure 8.3: Cumulated effect of QE on the 2-y, 5-y, 10-y EA sovereign yields and cumulated change in 10-y *(percentage points)*



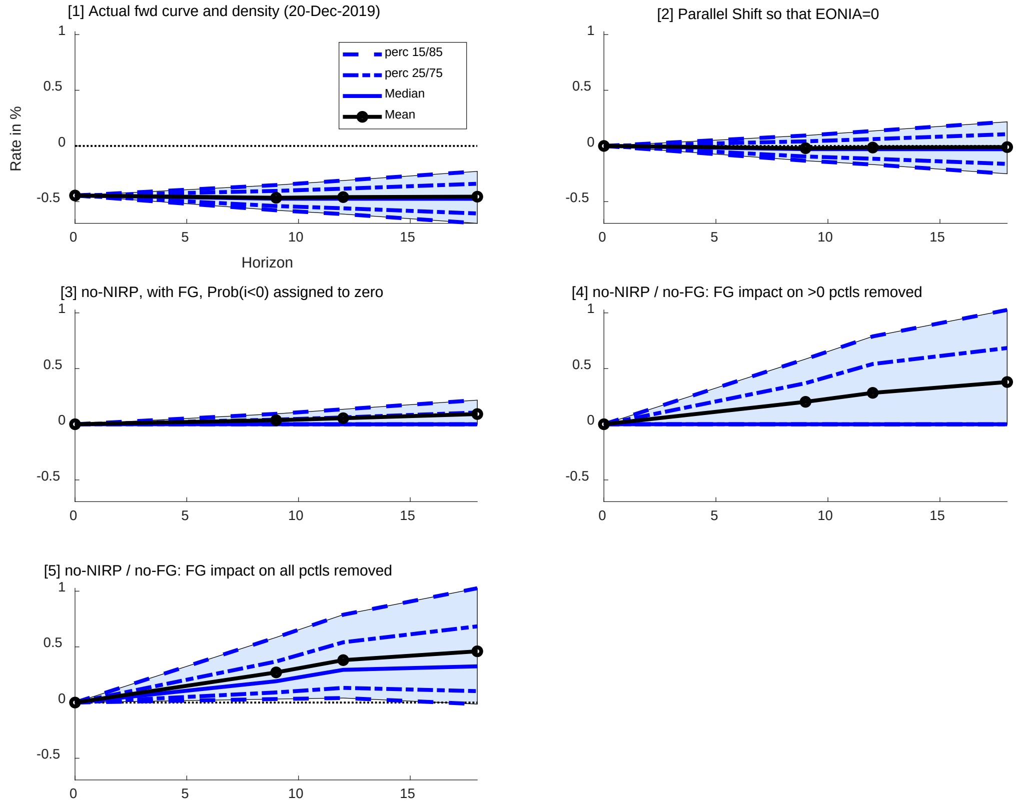
Notes: Figure 8.1 reports the actual cumulated changes in the Deposit Facility Rate (DFR) the overnight rate (Eonia), and the cumulated effect of the negative interest rate policy (NIRP) on the 3-month OIS forwards in 18-month; Figure 8.2 reports the cumulated effect of the negative interest rate policy (NIRP) and forward guidance (FG) on the 3-month OIS forwards in 18-month; Figure 8.3 shows the actual cumulated change in the euro area sovereign bond yields (black solid line) and the impact of the asset purchase programmes on the sovereign bond yield with 2,5, and 10 years maturity.

Figures 8.1 and 8.2 show the cumulative impacts of NIRP, as a standalone policy instrument (in what we refer to as a "*no*-NIRP *with* FG" counterfactual world) and in combination with FG ("*no*-NIRP / *no*-FG"), respectively, on the 3-month Eonia forward rate in 18 months. Concretely, in estimating those impacts, we proceed as follows. For each trading day in our sample, we start with the option-implied predictive densities for the 9-month, 12-month, and 18-month horizons.[24] We convert those densities from the Euribor to the OIS space, and we interpolate across the three densities to obtain smoothed longitudinal fan charts of the type shown in Figure 2. We have visualised the outcome of our procedure in Figure 3. Figure 9 provides a similar visualisation as Figure 3 but adds more detail on how the percentiles of the fan charts are treated along the way to generating the rate counterfactuals that are illustrated in Figures 8.1 and 8.2. The left panel in the first row of Figure 9 shows the density corresponding to 20 December 2019. The mean of the distribution is the forward curve, and we also show the median (solid blue line) and the 15th, 25th, 75th and 85th percentiles. The "*no*-NIRP *with* FG" counterfactual world is constructed in two steps. In a first step, we shift the entire distribution upward in a parallel fashion so as to re-anchor the three-month (spot) rate at zero. The idea is that, in a ZLB world – a *no*-NIRP constellation – the value of the overnight interest rate and the 3-month spot OIS rate would not be negative. However, while at this point of our procedure the non-negativity condition would apply to the very short end of the displaced density, if we stopped here, we would not rule out that lower percentiles of the predictive density might still range in negative territory over longer maturities. This is indeed the case for the specific example illustrated in the top-right panel of Figure 9. Therefore, in a second step, in order to generate a credible *no*-NIRP regime, one in which the central bank notoriously abstains from NIRP and investors accordingly have never observed negative rates (and firmly believe they will never see them in the future), we impose the ZLB condition *across horizons*. In other words, for each maturity, we counterfactually re-apportion the entire probability mass assigned in the displaced density to negative-rate realisations to a zero-rate realisation: see the left panel in the second row of Figure 9. The resulting density is a censored distribution, characterised by a 'point mass' of probability assigned to zero and a continuous density component for future possible rate outcomes above zero. For all horizons, the new counterfactual forward rate (black dots) is given by the mean of the censored distribution.[25] As expected, the counterfactual forward curve lies above the forward curve corresponding to the displaced distribution in the top-right panel. The difference between the two forward curves (the 'bias') is the pure result of the non-negativity restriction being imposed on all rate expectations expressed in this *no*-NIRP *with* FG world. What we show in Figure 8.1 is, indeed, how the impact of NIRP as a solo has evolved over time, i.e. the results of the exercise exemplified in Figure 9 applied to each day in the sample.

[24] The option-implied densities are estimated on a daily basis by ECB staff, see Puigvert-Gutiérrez and de Vincent-Humphreys (2012) for the methods deployed in that exercise.

[25] Implementation-wise we discretise for each horizon the option-implied density into a discrete distribution: we partition the rate outcome space into a fine grid of bins and compute for each bin the resulting probability. As a cross-check, the mean obtained as the scalar product of bin mid-points and corresponding bin probabilities is usually undistinguishable from the mean of the original PDF. For the "no-NIRP *with* FG" counterfactual we set probabilities of bins with sub-zero outcomes to zero and re-assign their original cumulated probability to the bin that contains zero. The mean of the new distribution is again the scalar product of bin-midpoints and probabilities.

Figure 9: Constructing the *no*-NIRP counterfactuals – From actual to "*no*-NIRP *with* FG", to "*no*-NIRP / *no*-FG"



Notes: For an arbitrary date (20 Dec 2019), the Figure illustrates the approach for quantifying the impact of NIRP and FG on the forward curve via manipulation of option-implied densities. See the main text for details.

Why do we consider the distribution shown in the left panel of the second row as representative of a *no*-NIRP regime *with* FG? While the censoring at zero reflects the assumption that market participants rule out negative rates, the upper part of the distribution is assumed to be unchanged. Indeed, in this ZLB world, we assume that the ECB would have expressed the intention to keep the path of the overnight rate flat at zero for as long as it did pledge to keep the policy rates at the "*current level*" in history through increasingly explicit guidance. In response to this information, while "*pessimists*" in the counterfactual "no-NIRP *with* FG" world would have found no reason to expect an earlier time of rate lift-off than they did in history, and thus would have maintained a prediction for a rate path flat at zero throughout the 18-month horizon, our baseline assumption is that "*optimists*" would have priced in the same probability of rate hikes in the near future and expressed the same conviction about the speed of rate adjustment following lift-off as are embodied in the sequence of historical option-derived PDFs. This latter behavioural assumption about "*optimists*" is debatable, though. Below we show that a ZLB policy would have led to a significantly weaker economy: wouldn't a worse outlook have convinced the "*optimists*" to shift their expectations of policy in a dovish direction and incorporate a flatter rate trajectory in their option contracts? We address this question in Section 6.

In order for us to be able to isolate the impact of FG, we need to transition from a "*no*-NIRP *with* FG" world into another one in which the ECB hypothetically would have released no indications about the expected timing of lift-off, or even about the future direction of the policy rate. Our methodology for doing so makes use of the results we obtain from the event study exercise when the left-hand variable of equation (1) is $\Delta f^{\tau}_{\mathrm{p,t}}$ and *p* indicates the percentiles of our option-derived distributions 9, 12 and 18 months ahead. Specifically, we cumulate the impact of the FG-related event dummies, $D_{\mathrm{j,t}}$ (see Table 2) on such upper percentiles over time, and subtract that estimated (negative) impact from the upper percentiles of displaced, censored distributions which we consider representative of a "*no*-NIRP *with* FG" regime. In more detail, if $\delta^{\tau}_{\mathrm{p,t}}$ denotes the cumulated impact of FG events at time t on the pth percentile τ month-steps ahead,[26] at time *t*, for any horizon τ, we check for the "*no*-NIRP *with* FG" counterfactual distribution which of its percentiles $f^{\tau}_{p,t}$, *p*= $\{0.05, 0.15, 0.25, 0.35, 0.45, 0.5, 0.55, 0.65, 0.75, 0.85, 0.95\}$ are positive. For all those percentiles, the new counterfactual percentiles corresponding to the "*no*-NIRP / *no*-FG" world, $f^{\tau\,\prime}_{p,t}$, are given by $f^{\tau\,\prime}_{p,t} = f^{\tau}_{p,t} + \delta^{\tau}_{p,t}$. The fan chart that corresponds to the "*no*-NIRP / *no*-FG" regime is the right panel in the second row of Figure 9.[27] The percentiles have been lifted (relative to the "*no*-NIRP, *with* FG" stage, i.e. the middle-left panel) as described, and the new means (black circles) are estimated based on the new percentiles.[28] As an alternative approach for constructing the "*no*-NIRP / *no*-FG" scenario, we modify all percentiles (no matter if above or at zero) and lift them via the respective estimated FG regression coefficients, see lower-left panel in Figure 9. Figure 8.2 is the evolution of the joint impact of the two policies, NIRP and FG, obtained from the construction of the "*no*-NIRP / *no*-FG" scenario (using the last variant, in which all percentiles are being lifted).

As evident in Figure 8.1, the ECB's decision to break into negative ground in 2014 with the DFR (the red line) obviously eased monetary policy over and beyond what would have been feasible if the ECB had chosen to respect the ZLB, as it pulled the overnight interest rate, the Eonia, in the same direction (the blue line). But the decision to shatter the ZLB yielded an extra easing dividend. By altering investors'

[26] Adding the estimated λ and ϑ in equation (1) above for the respective event, the respective horizon τ and percentile p provides the two-day impact of the event on the percentile. Cumulating over time provides $\delta^{\tau}_{p,t}$. The econometric estimates provide results for percentiles $p = 0.15, 0.25, 0.35, 0.45, 0.5, 0.55, 0.65, 0.75, 0.85$. For the counterfactual scenarios using additionally the 0.05 and 0.95 percentiles proved useful, which were extrapolated at each time and horizon from the profile of the nine estimated percentile impacts.

[27] Note that in the particular example shown in the Figure, the median in the "no-NIRP *with* FG" distribution is zero at a 12-month horizon, and above zero at an 18-month horizon, so the former is not affected by the adjustment subtracting the effect of FG, while the latter is affected.

[28] The counterfactual distribution is described by the eleven percentiles. Based on those, we approximate a discrete distribution (essentially assigning the percentile-implied interval probabilities to the mid points of the intervals) and compute the means based on that distribution. As an alternative approach, the method expounded in Adrian *et al.* (2019) could be applied, i.e. fitting a parametric distribution that matches the percentiles, and then the mean would be implied by the fitted distribution. Their choice (skewed-t) would not be applicable here, though, as our distribution is censored, but fitting a censored normal or normal mixture could be conceivable as an alternative.

beliefs about the location of the lower bound and the likelihood of seeing further DFR cuts further down the line, it magnified the effect of the DFR reductions on intermediate-maturity money market interest rates. Overall, in cumulative terms, in the period between June 2014 and June 2020, NIRP has compressed the 3-month in 18-month forward rate (the black line in the left panel) by 65bp, 20bp more than the cumulative reductions in the DFR that have occurred over the same period can explain.

FG added further accommodation by compressing the upper tail of the predictive distributions. The black line in Figure 8.2 shows the cumulative impact of NIRP and FG on the 3-month in 18-month forward rate. The FG impact is computed by applying the FG coefficients to all percentiles of the no-NIRP-with-FG distribution (i.e. corresponding to the lower-left panel of Figure 9). In case we only shift up the positive percentiles in order to emulate the no-FG world (the approach sketched in the middle-right panel of Figure 9), the estimated effect of FG is up to 20 bps less distinct. Subtracting from those cumulative impacts the clean NIRP contribution represented by the black line in Figure 8.1, we conclude that, on net, FG in isolation as of June 2020 explained around 20 bp of the cumulative decline in the forward rate.

5. Macro counterfactuals

To complete our analysis of impacts, we quantify the transmission of the ECB policy measures via macro-econometric simulations. Our approach is agnostic about the mechanisms of transmission. Accordingly, we base our macroeconomic analysis of the ECB's unconventional instruments on a large Bayesian VAR, which does not incorporate potent expectations channels but offers satisfactory empirical fit and requires minimal identifying restrictions.[29] The Bayesian VAR takes the following form:

$$Y_{i,t} = c_i + \sum_{j=1}^{4} A_{i,j} Y_{i,t-j} + u_{i,t} \qquad (2)$$

where the vector of endogenous variables, $Y_{\mathrm{i,t}}$ consists of 17 variables: unemployment rate, real GDP, HICP inflation, loans to non-financial corporations, loans to households, the Eonia, the 3-month Eonia forward in 12 and 18 months, the 2- 5- and 10-year euro area sovereign yields, the lending rate on loans to non-financial corporations and households, the interest rate rates applied to deposits of non-financial corporations and households, the Euro/US dollar exchange rate and the stock market index. The overall

[29] An evaluative method based on a structural model has many advantages, including discipline and coherence with theory. But it has one non-trivial drawback: the need to make very strong propositions about, e.g., the impact of policy pronouncements on agents' expectations (see below). In addition, while DSGE models, specifically, have recently been enriched by including a detailed modelling of unconventional measures, they have tended to focus on one specific type of measure and one specific transmission mechanism at the time. Gertler and Karadi (2013), for example, concentrate on QE and on characteristic frictions to explain its transmission. Furthermore, to limit complexity, the modelling of QE has largely abstracted from induced shifts in "term" premia, which – as a vast term structure empirical literature demonstrates – is a critical factor in explaining the reaction of long-term yields to QE measures. We therefore regard our agnostic approach based on a large BVAR with minimal identifying restriction as a more robust avenue.

estimation sample used in the empirical analysis starts in the first quarter of 1999 and ends in the fourth quarter of 2019.

Classical maximum likelihood estimation techniques are not feasible. They would provide unreliable estimates in a model with as large a cross-section of variables and as rich an autoregressive structure (with 4 lags, which maximize conventional information criteria) as we include in our analysis, considering the relatively small sample of data points we can use. The high dimensional data problem is addressed by estimating the model using bayesian shrinkage.[30] More specifically, we consider conjugate priors belonging to the Normal/Inverse-Wishart family, where the prior for the covariance matrix of the residuals is an inverse Wishart distribution and the prior for the autoregressive coefficients is normal. Concerning the prior on the covariance matrix of the errors, Σ, the degrees of freedom are set to $n+2$, i.e. to the minimum value that guarantees the existence of the prior mean, which we set as $\mathrm{E}[\Sigma] = \Psi$, where Ψ is diagonal. The baseline prior on the model coefficients is a Minnesota prior (see Litterman, 1979) centered on the assumption that each variable follows an independent random walk process. The prior moments for the VAR coefficients are as follows:

$$E\left[(A)_{ij} | \Sigma, \lambda, \Psi\right] = \begin{cases} 1, if\ i = j, and\ s = 1 \\ 0, \quad otherwise \end{cases}$$

$$cov[(A)_{ij}, (A)_{hm} | \Sigma, \lambda, \Psi] = \begin{cases} \lambda^2 \dfrac{1}{s^2} \dfrac{\Sigma_{ih}}{\psi_j}, \quad if\ m = j\ and\ r = s \\ \quad 0, \qquad otherwise, \end{cases}$$

where the variance of the prior is lower for the coefficients associated with more distant lags, and the coefficients associated with the same variable and lag in different equations are allowed to be correlated. The terms $\frac{\Sigma_{ih}}{\psi_j}$ account for the relative scale of the variables. Moreover, the hyperparameter λ controls the scale of all the variances and covariances, and effectively determines the overall tightness of the prior. Finally, we use a non-informative for the constant. Following Doan, Litterman, and Sims (1984), we set an additional prior centered at 1 for the sum of the coefficients on each variable's own lags, and at 0 for the sum of the coefficients on other variables' lags. This prior also introduces correlation among the coefficients on each variable in each equation. The tightness of this additional prior is controlled by the hyperparameter μ. As μ goes to infinity the prior becomes diffuse; as it goes to 0, we approach the case of exact differencing, which implies the presence of a unit root in each equation. Overall, the exact setting of these priors depends on the hyperparameters λ, μ and Ψ, which reflect the informativeness of the prior distributions for the model coefficients. We follow Giannone, Lenza, and Primiceri (2015) and treat the hyper-parameters as additional parameters, with almost flat prior distributions. In this set up, the marginal likelihood evaluated at the posterior mode of the hyperparameters is close to its maximum.

[30] See De Mol, Giannone, and Reichlin (2008). The latter paper shows that, if the data are collinear, as it is the case for macroeconomic variables, the relevant sample information is not lost when over-fitting is controlled for by shrinkage via the imposition of priors on the parameters of the model to be estimated.

For purposes of constructing our macro counterfactuals, we partition the set of endogenous variables into three subsets: the slow moving macroeconomic variables (y_{1t}), the policy variables (z_t), and the fast-moving non-policy variables (y_{2t}). More precisely, unemployment, GDP, inflation and lending volumes are included in y_{1t}. The set of variables in the vector z_t, instead, changes according to the policy considered in the simulation. For simulating the macroeconomic effects of QE, z_t contains the 2-, 5-, and 10-year sovereign bond yields, and we impose that the impact of QE on those variables is the one shown in Figure 8.3. In other words, we add the QE-induced decline in the term premia for sovereign bonds with maturities of 2-, 5-, and 10-year shown in Figure 8.3 to the observed yields and the model is simulated conditional on the resulting counterfactual yields and the historical path of short-term interest rates. When simulating the impact of NIRP and FG, z_t contains the Eonia spot rate, as well as the 3-month Eonia forward 12 and 18 months ahead, and we impose that the impact of the two policies on those variables is the outcome of the methodology we present above: for example, in gauging the magnitude of the effects of NIRP, the time series of its impacts on the forward rate 18 months out shown in Figure 8.1 is added to the historical path of the same variable as a conditioning variable for simulating the macroeconomic impact of NIRP. All variables not included in y_{1t} or z_t are included in y_{2t}.

In our model-based evaluation of the quantitative effects of the three unconventional policies on the economy, a no-policy scenario is compared with a policy scenario. The historical developments of the endogenous variables capture the policy scenario.[31] In the no-policy scenario, we construct the conditioning path for the policy variables (z_t) by applying to their conditional forecast the policy impacts that we document in Figure 8. In the exercise, while the set of slow-moving macroeconomic variables are prevented from reacting to the policy on impact, but do so only over time, the fast-moving endogenous variables, including stock prices and the exchange rate, are allowed to jump contemporaneously. These restrictions are an important feature of our methodology because they help to tell apart the monetary policy impulse from other demand shocks. These restrictions amount to a timing restriction of the sort used in the literature on the impact of monetary policy shocks identified using a recursive scheme, in which macroeconomic variables such as economic activity and inflation are not allowed to move in response to an impulse.[32]

[31] As the results are computed in terms of deviations from the no-policy scenarios in a linear VAR model, the assessment is independent of the path assumed for the no-policy scenario.

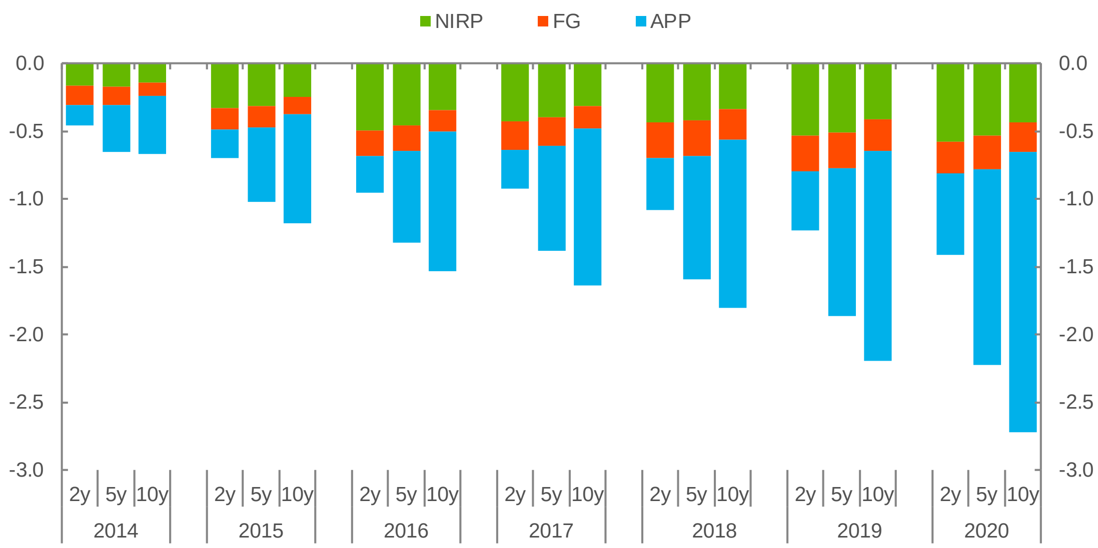
[32] Without imposing some identification restrictions of the type we use, conditional forecasts in VARs may not be well suited to compute the response to monetary policy shocks because (i) the conditioning path on interest rates would be fulfilled by using a combination of shocks weighted by their relative variance in sample, and (ii) in a typical sample, the contribution of monetary policy shocks may be small and therefore the conditional forecast would pick up mainly non-monetary policy shocks. Our restrictions help to tilt the balance towards monetary policy shocks. In addition, over the last several years monetary policy interventions have been very large, making it easier for our methodology to correctly infer monetary policy. To the extent that our results may still confound accommodative policy shocks (bringing down interest rates) with negative demand shocks (bringing down interest rates), our quantification of the impact of the policy measures would be an underestimation in that the boost in inflation and

Formally the impact of the policy instruments is measured by a time series of responses in the endogenous variable being simulated, u_{t+h}, where:

$$u_{t+h} = E(y_{1t+h}|\Omega_t, z_{t,\dots t+h}) - E(y_{1t+h}|\Omega_t, z^*_{t,\dots t+h}),$$

Ω_t stands for the state of the economy at time *t*, $y_{1,t+h}$ denotes the path of non-policy variables up to horizon *h*, z^*_{t+h} is the conditioning path of the policy variable, and z_{t+h} is the unconditional path for the relevant policy variable (see Canova, 2007; Altavilla, Giannone and Lenza, 2016; and Altavilla, Canova and Ciccarelli, 2020).

Figure 10: Impact of non-standard measures on sovereign yields *(percentage points)*



Last observation: June 2020.

Before moving to the estimated macroeconomic effects of the three unconventional measures that we analyse in this paper, we document their propagation across the sovereign yield curve, a critical link in monetary transmission. Figure 10 shows the term structure of impacts on the sovereign yield curve. Two features of Figure 10 are particularly noteworthy. First, since its adoption in June 2014, NIRP has exerted a sizeable influence on the sovereign curve throughout maturities. The magnitude of the response in long-term interest rates to the NIRP impulse exceeds by a wide margin the extent to which long rates are estimated to react to conventional policy cuts. As a term of comparison, based on the model-implied peak effect of a standardized reduction in the Eonia on long-term sovereign rates away from the lower bound, it would have taken in positive-rate times a 150bp cut to the very short term interest rate to bring about, two to three years out, the 20bp reduction in the 10-year yield that NIRP generated by 2017 – with only three 10bp prior rate reductions implemented in June 2014, December 2015 and March 2016. Said

economic activity would be even larger than the one we find and document in Figures 11.1, 11.2 and 11.3 because negative demand shocks would bring interest rates down but at the same time also inflation and activity would decline.

differently, in conventional monetary policy times, it is short rates that load most heavily on policy rate reductions, with the impact fading quickly across the maturity spectrum. By contrast, NIRP reaches maximal impact at a 5-year maturity and the downward pressure on longer-term rates remains very significant through a 10-year maturity (see also Altavilla *et al.*, 2019).

Second, QE explains the lion's share of effects, particularly over the back end of the yield curve. After scaling the ECB's bond portfolio accumulated or expected to be accumulated under APP and PEPP in June 2020 to the euro area 2019 GDP, the ECB's QE programme seems to have been approximately as effective in providing monetary policy ease by compressing long-term interest rates as equivalent large-scale asset purchase programmes executed by other central banks. Compared with the Federal Reserve's LSAP, for example, the impact of the ECB's QE programme of around 200bp stands toward the upper end of the range of estimates available for the various rounds of LSAPs. Such impact estimates vary in size according to the methodology adopted by the researchers, being comparatively smaller for studies based on models of the term structure of interest rates such as Ihrig *et al.* (2018) – which puts the overall effect on the 10-year Treasury yield at 125bp – and relatively stronger for event studies using many events – Altavilla and Giannone (2017), in the latter category of studies.

Having quantified the impacts of the ECB's three unconventional policy actions on market rates, we now document the effects of these actions on aggregate economic activity and inflation over the past few years. We do so in Figures 11.1, 11.2 and 11.3, where we show the time series of impacts on the 17 variables considered in our BVAR (the blue lines in the 17 panels of the three figures refer to median estimates for NIRP, FG and APP, respectively). In generating those estimates, we have calibrated the model with the numerical value of the coefficients estimated over the entire sample ending in the fourth quarter of 2019. [33] To start, note the different conditioning protocols followed in generating the NIRP, FG and QE counterfactuals. When simulating NIRP, the cumulative changes in the Eonia are set equal to the historically observed trajectory of cumulative Eonia changes since 2013, while the path of cumulative adjustments in the two forward rates on which the macro scenario is conditioned are set equal to the estimated cumulative impact of NIRP on those two variables (whose daily values are shown along the black line of Figure 8.1), and the three sovereign yields are let free to change endogenously. When simulating FG, consistent with the ZLB world in which FG is evaluated, the Eonia is kept constant at zero, while the path of cumulative adjustments in the two forward rates are set equal to the estimated cumulative impact of FG on those respective forward rates (Figure 8.2 reports the sum of the FG and NIRP impacts as a black line). For the QE simulations, the conditioning variables are the three sovereign bond yields considered in our analysis, whose cumulative adjustments are set equal to the estimated cumulative effects of QE on the 2-year, 5-year and 10-year yields (see the blue line in Figure 8.3, and the blue bars in Figure 10). We neutralise any feed-back that the QE-induced lower interest rates on the long

[33] While the inference discussed in this section extends through June 2020, our baseline estimation does not utilise the first semester of 2020, as we consider the data collected over the period of market turbulence unleashed by the Covid-19 pandemic as scarcely informative as to the dynamic properties of the euro area economy.

end of the yield curve typically has on the front end of the curve by keeping the two forward rates constant. The latter point is worth highlighting. In general, if the bond purchases have the desired effect of accelerating economic recovery and spurring reflation, investors tend to react to the brightening outlook by bringing forward the date on which they expect the central bank to start raising its policy rates, thus twisting the forward curve into a steeper shape. This is indeed what would happen in the model, if short interest rates were left free to adjust to the lower term premia brought on by QE. Therefore, in keeping with the way we derive the QE effects – seeking a clean curve-flattening shock of QE recalibrations by orthogonalising the adjustment in observed yields with respect to changes in the 3-month spot OIS rate and the 3-month in 18 months forward rate – we deactivate such feed-back channels by preventing the 3-month OIS rate and the forward rate 18 month out to move as the QE effects are fed into the model.

While considerable uncertainty attends some of the estimates, the quantitative assessment emerging from Figures 11.2, 11.2 and 11.3 suggests that the actual stimulus to the economy and inflation imparted by the three policies since 2013 has been economically substantial and very persistent. Mirroring the relative impacts on the term structure of interest rates, we identify a ranking in the potency of the three instruments, seeing QE as the most impactful tool, followed by NIRP and, finally, FG. The comparatively muted impact of FG – notably on output growth (see the narrowly significant time series of GDP growth effects in the second panel of the first row of Figure 11.2) – could be ascribed to the non-committal FG formulations adopted by the ECB, but is nonetheless striking if compared with other studies. Two elements of our methodology can help explain this discrepancy in inferences. First, we do not *assume* that the anticipations of policy in the distant future can be arbitrarily changed by verbal guidance, but rather we *measure* the magnitude of the adjustments that the history of the ECB's verbal guidance has caused on such anticipations, taking the different percentiles of the factual predictive rate densities as the metric for the public perceptions of the ECB's policy intentions moving forward. Second, while in forward-looking models – mostly dynamic stochastic general equilibrium models built around a representative household with rational expectations – adjustments in expectations turn out to be a powerful tool for stimulating the economy at the ELB, in our model setting this channel is essentially shut down. The appropriateness of our modelling choice can be assessed from two perspectives. On one hand, one could argue that expectational effects are no small factors in monetary policy transmission, and in fact they are of particular relevance in the circumstances of the past few years, when the public has had to rely disproportionately on policy announcements for forming expectations, because there was no past record of unconventional policy actions to go by. So, our neglect of such channels may be seen as a limitation of the approach taken here. On the other hand, models that emphasise these expectations channels estimate macroeconomic effects of FG that are so powerful that some researchers have developed doubts about the theoretical models themselves (see, for example, Del Negro, Giannoni and Patterson (2012) and McKay, Nakamura and Steinsson (2016)). Overall, we view the first, event study stage of our FG assessment procedure as realistic, while we acknowledge that the second, macroeconomic simulation stage inevitably biases our results for FG downward.

Perhaps surprisingly, given the rather circumspect tactic adopted by the ECB in reducing its policy rates below zero, NIRP is estimated to have boosted activity and inflation quite measurably. The support to annual GDP growth from NIRP has reached a peak of 0.3pp in 2018, while its contribution to annual inflation has grown over time to stabilise around 0.2pp by the end of the period covered. The impulse imparted by QE to growth and prices has been very substantial and much more persistent than for any other instrument. The effects on GDP growth have been building up quickly to hit 0.7pp in 2018 and 0.8pp by June 2020, as the new aggressive wave of QE-related declines in yields over 2019 (see Figure 5 and Figure 8.3) kept the upward momentum elevated. Transmission to unemployment has been slower to kick in, but has continued rising through the end of the observation period. The QE effects on HICP inflation are more subdued and less significant, although strengthening over time, as the accumulating effects of the monetary policy impulses gradually push the economy to test its capacity constraints. Summing up the effects of the three policies, we conclude that in 2019 GDP growth and annual inflation would have been 1.1 p.p. and 0.75 p.p. lower, respectively, and the unemployment rate 1.1 p.p. higher than they actually were, had the ECB abstained from using NIRP, FG and QE over the previous six years or so.

While measurable, these impacts are smaller but more protracted than those documented in most of the recent literature on the impact of LSAPs on the U.S. economy. If we rescale our results to make them comparable, we find that asset purchases by the ECB amounting to 1% of the 2014 euro area GDP have led to an increase in GDP of 0.12% by end-2019. Looking at the US, the studies most directly comparable to our analysis are Engen *et al.* (2015), Dahlhaus *et al.* (2018) and Baumeister and Benati (2013), which also consider quarterly GDP.[34] The former two papers find that asset purchases amounting to 1% of the 2009Q1 US GDP led to an increase in output by 0.2pp (peak impact), while the latter finds a larger peak increase, in the order of 0.5%. A notable exception in the LSAP literature is Chen *et al.* (2011), which finds that the peak impact on output is significantly smaller, 0.02%. Other studies, including a monthly index of economic activity, generally arrive at higher figures. For instance, Kim *et al.* (2020) finds a peak impact on industrial production of 0.5%, while Weale and Wieladek (2016) and Hesse *et al.* (2018) find a peak impact on a monthly series of GDP of almost 0.6% and 0.2%, respectively. There are fewer studies focusing on the euro area, none examining the effect of PEPP, the pandemic emergency programme launched in March 2020. Normalising the asset purchases under the APP to 1% of the 2016 euro area GDP, several papers, such as Andrade *et al.* (2016), Burlon *et al.* (2019), Cova *et al.* (2019), Kuehl (2018), Mouabbi and Sahuc (2019) and Sahuc (2016) employ a quarterly DSGE model. Across these studies, whose peak growth impact estimates range between 0.02% and slightly above 0.2%, our results

[34] We report results for the U.S. by rescaling the size of asset purchases to amount to 1% of 2009Q1 GDP in order to ensure comparability across studies.

are positioned exactly mid-range. Our results are at upper range instead when assessed against papers employing a SVAR model. For example, Gambetti and Musso (2017), using quarterly GDP, finds an increase in output by 0.02%, while Wieladek and Pascual (2016), using a monthly measure of GDP, and Lhuissier and Nguyen (2021), using industrial production, find an increase by 0.1%.

Overall, there are reasons to think that our results understate the effectiveness of the ECB's unconventional policy actions. We mentioned above how our methodology could discount the traction exerted by FG. As for QE, the first round of asset purchases, in particular, is often credited with having definitely restored confidence in the euro area project, a mechanism that our model does not incorporate. If confidence, business sentiment, and investors' assessments of risks would have been even more impaired in the absence of QE, NIRP and FG, then the counterfactual simulations may significantly understate their actual efficacy at least in the early stages of their implementation.

It is interesting to trace the propagation pattern of NIRP and QE through the financial system. NIRP has compressed bank lending rates in general, and those applied on loans to enterprises in particular. This likely owes to the substantial pass-through of NIRP into mid-maturity OIS rates, which are pivotal in the pricing of commercial loans in the euro area. QE has exerted a comparatively more pronounced impact on mortgage rates, as the latter are more responsive to the far end of the sovereign yield curve, where the influence of QE is most noticeable.[35] The same mechanism – working through suppression of long-term sovereign yields – explains the strong expansionary effect of QE on loan volumes. As documented in an important literature, the bank capital channel is a critical driver of loan creation.[36] Our model captures this channel indirectly, as sustained declines in long-term interest rates – by generating valuation gains on banks' bond portfolios – historically have tended to correlate tightly with loan volumes. Early cuts in negative grounds have depreciated the euro vis-à-vis the dollar and supported euro area stock prices, although both effects seem to have waned over more recent periods. The exchange rate and stock market effects of QE have been slower to materialise – with even a short-lived perverse impact on the value of the euro at the start of the programme, when the expectations of a QE announcement unleashed a sizeable inflow of international capital into the euro area. But both effects have shown a tendency to intensify over time.

As a complement to the evidence documented above, Figures 12.1 and 12.2 show the findings of real-time impulse responses to standardised NIRP and QE actions, respectively, taken at different points in time. Figure 12.1 traces out the propagation of three 10bp cuts in negative territory, dated September 2014, March 2016 and September 2019, assuming in all three episodes the typical impact adjustment in the forward curve that we estimate for NIRP over our sample (see Figure 8.1). Concretely, the impulse we

[35] The pricing of loans tends to be linked to the respective duration which tends to be longer for mortgages than for loans to firms. See, e.g. Hoffmann, Langfield, Pierobon, and Vuillemey, 2019.

[36] See Kashyap and Stein (1995), Kishan and Opiela (2000) and Van den Heuvel (2002) for evidence on the importance of bank capital in influencing bank lending behaviour and the transmission of monetary policy actions.

imagine was introduced on each of those dates is the end-of-period cumulative impact we estimate for NIRP (the last point in the black line in Figure 8.1) divided by five, the number of times the ECB reduced its DFR to negative levels by 10bp since 2014. Differently from the simulation methodology followed to generate Figure 11.1, in constructing the impulse responses to the three NIRP shocks shown in Figure 12.1, we use calibrated versions of our BVAR that incorporate numerical values for the coefficients that are estimated over different samples. The impulse responses associated with the September 2014 decision are conducted on the basis of model estimates using a sample that spans data between 1999Q1 and 2014Q3. The sample used to generate the impulse response to the March 2016 decision includes data from 1999Q1 to 2015Q4, and so on. By using only windows of data available to the policymakers at the time of the announcements, we want to measure the extent to which each decision was seen as contributing to the attainment of the ECB's statutory objective in real time. Furthermore, by comparing impulse responses across the three episodes, we can test whether the macroeconomic impact of the measure has varied over time according to the market conditions prevailing on the date of the announcement, or because of intervening structural change in the economy, or simply because the systematic recourse to unconventional policies on the part of the ECB might have gradually altered public perceptions of the future responsiveness of the Governing Council to changes in economic conditions. A couple of interesting findings emerge from our analysis. First, as also apparent in the time series of macroeconomic effects shown in Figure 11.1, the three rate decisions seem to have followed steeper paths of transmission to real activity, while the effects on inflation have been more muted and delayed. Second, the earliest DFR reduction considered, hypothetically dated September 2014, appears to have spurred marginally larger responses in all variables than the two later ones, possibly because the decision was announced and implemented at a time when market conditions in the euro area were still strained and risk premia were atypically large. This being said, we are unable to detect significant diminishing returns across the three episodes for what concerns their economic propagation.

Inspection of Figure 12.2 leads to similar conclusions. The picture shows responses to the changes in the ECB's steady state QE portfolio announced in January 2015 (the start of the programme), December 2017 (extension of the purchases into a more distant future but with a taper of the monthly purchase amounts) and September 2019 (re-launch of net purchases at a monthly rate of €20 billion, to be ended "*shortly before*" the date of rate lift-off). As the quantitative announcements that the ECB actually made on those three dates were vastly different in terms of size across the three episodes, we normalise the ECB's delivery of a higher QE portfolio to a €500 billion increase.[37] The simulations involve three stages. We first retrieve the overall estimated impacts of the three announcements on the sovereign interest rates.

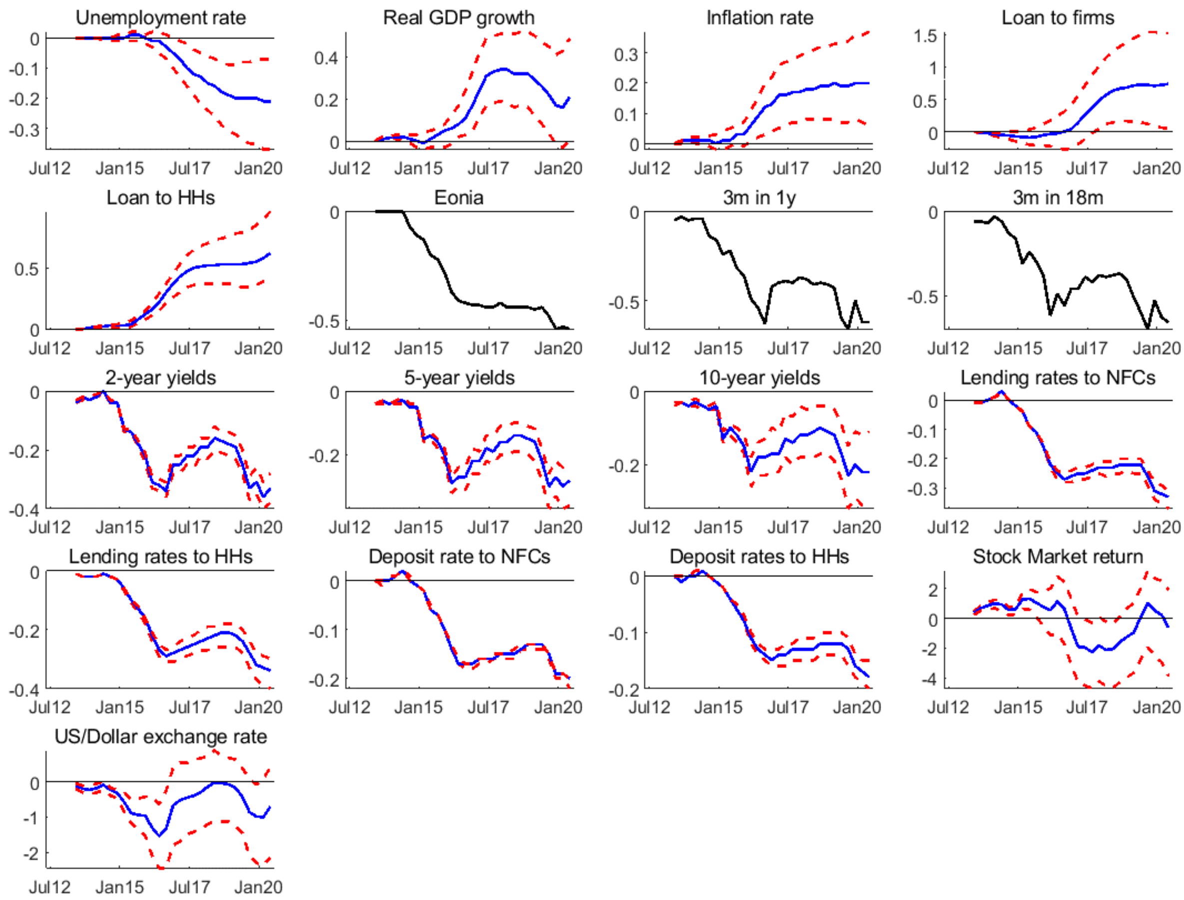
[37] The actual quantitative announcements were €1140 billion in January 2015, €315 billion in October 2017 (including the €45 billion envelope for the tapering phase to be executed over the second half of 2018 that was formally communicated at the June 2018 Governing Council meeting: see Table 4), and an estimated €580 billion in September 2019. The "open ended" nature of the latter announcement is converted into a stock figure by reference to the revisions in the expectation of ECB's APP holdings reported by the SMA survey following the decision.

Essentially, we sum up the announcement effects on the sovereign interest rates documented in Table 2 (the corresponding dummy coefficients) and the estimated impacts resulting from prior QE expectations built in the run-up to the three announcements (multiplying the estimated coefficient attached to ΔE_t^{QE} in our event study regression, as reported in Table 3, by the change in the QE portfolio expectations in the run up to the announcements). We report the yield effects encompassing announcement plus prior expectations formation effects for all the QE (re)calibrations in Table 4. We then rescale these rate effects to a standardised €500 billion shock. Finally, we simulate the overall rate impacts thus obtained for the three selected episodes using three versions of the model: for the simulation corresponding to the January 2015 announcement, the coefficients are estimated using data up to 2014Q1, while the simulations of the October 2017 and September 2019 use data up to 2017Q3 and 2019Q2, respectively. Note the steep path of responses in the real economy. Interestingly, inflation impacts are slow to emerge – and slightly more sluggish for earlier than later QE actions – but steadily increasing over time, as the economic slack is reabsorbed. The first announcement in January 2015 is an outlier in terms of the magnitude of its effects on real growth. But, once again, our findings tend to reject the notion that unconventional policies, and QE in particular, are only effective during periods of financial disruption or in their early stages of execution. There are two sides to this proposition: constancy of impacts of equally-sized asset purchase recalibrations on market yields, and invariance of transmission of a given yield adjustment that might results from those recalibrations. On the market-impact dimension, we find little affirmative evidence that subsequent rounds of QE recalibrations displayed diminishing efficacy in any measurable sense. Instead we find that the estimated sensitivities of the 10-year yield to the sequence of QE recalibrations shown in Table 4, with only one exception, are rather stable numerically.[38] Besides the role of expectations, two factors might be at play altering the effect of a unit increase in asset purchases in countervailing directions as time progresses. One is the lower quantity of duration risk held by private investors as the ECB, over time, has been withdrawing an increasing volume of bonds from the market's "free float". This has implied a shift on the side of the ECB, as a large bond investor, towards bond sellers with higher and higher reservation prices, which in turn might have boosted the extent to which a given euro amount of bond buys bid up prices. The other influence, working in the opposite direction, is related to the amount of residual duration risk present in a representative security traded in the market. As duration risk is a function of the realised volatility of bond yields and the latter is suppressed as interest rates grind lower (see King (2019), there might be little duration risk left to absorb in any single dated bond eligible under the ECB's purchases. This may degrade the responsiveness of bond yields to secondary market purchases

[38] The exception refers to the December 2016 announcement that the ECB would extend its bond purchases by at least nine months – and end them not before December 2017 – and lower the monthly purchases per month from €80 billion to €60 billion. One should note, however, that the announcement entailed two important tweaks to the rules that had been presiding over the composition of purchases. First, the minimum maturity of securities eligible under the public sector purchase programme was lowered from two years to one year. Second, securities with a yield to maturity below the DFR became also eligible. These announcements likely led investors to expect less duration extraction from the ECB's QE programme than had been the case before, which likely contributed to dampening the overall impact of the announced increase in the size of the ECB's bond portfolio.

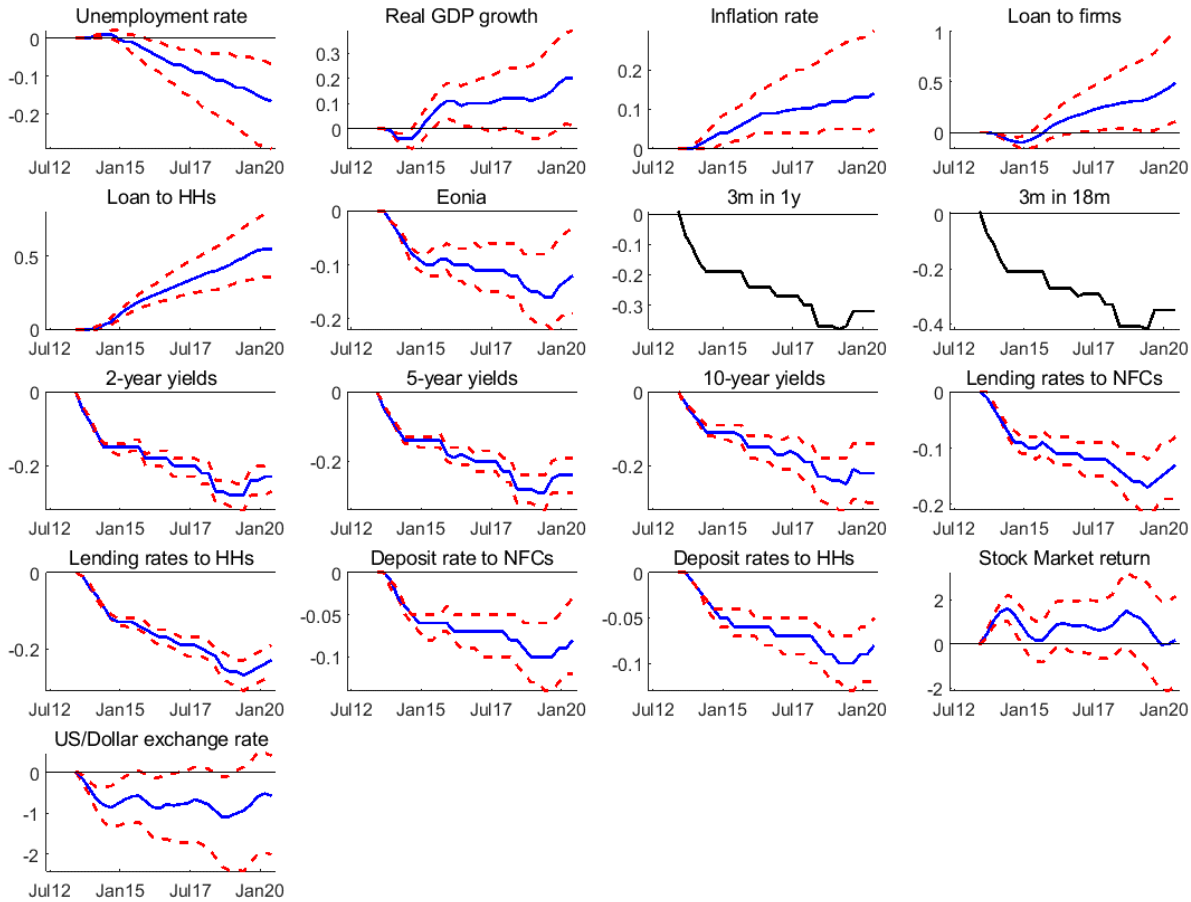
as time passes. As for macroeconomic transmission, we fail to detect significant variation in the timing and strength of the economy's response to the policy impulse.

Figure 11.1: The macroeconomic impacts of NIRP



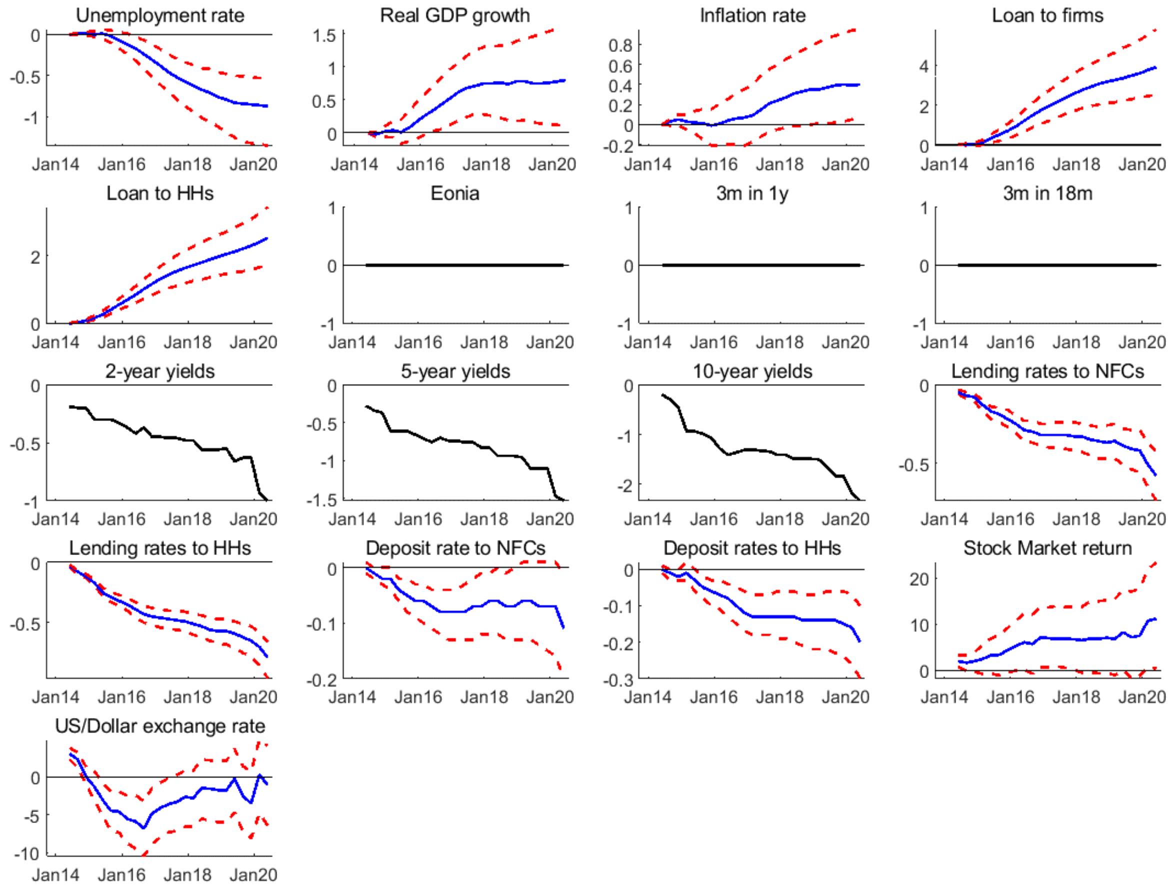
Notes: Model estimated over the whole sample: 1999Q1 to 2019Q4. Black solid lines denote the conditioning paths, i.e. the estimated cumulated effect of NIRP on policy variables as reported in Figure 8. Blue lines denote the impact of NIRP on macroeconomic variables and other variables All variables (including conditioning rate variables) are expressed in deviation from baseline. Real GDP growth, inflation rate, loan to firms and loan to households are expressed in annual changes; in percentage points.

Figure 11.2: The macroeconomic impacts of FG



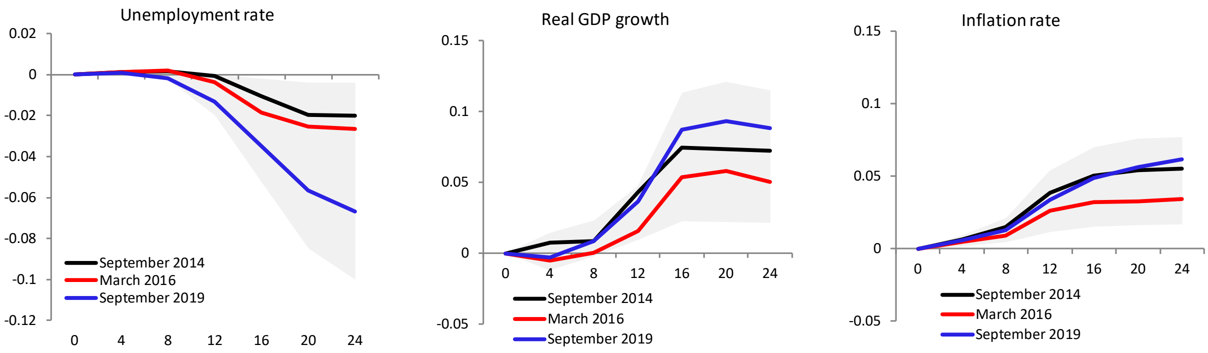
Notes: Model estimated over the whole sample: 1999Q1 to 2019Q4. Black solid lines denote the conditioning paths, i.e. the estimated cumulated effect of forward guidance on policy variables as reported in Figure 8. Blue lines denote the impact of FG on macroeconomic variables and other variables. All variables (including conditioning rate variables) are expressed in deviation from baseline. Real GDP growth, inflation rate, loan to firms and loan to households are expressed in annual changes; in percentage points.

Figure 11.3: The macroeconomic impacts of QE



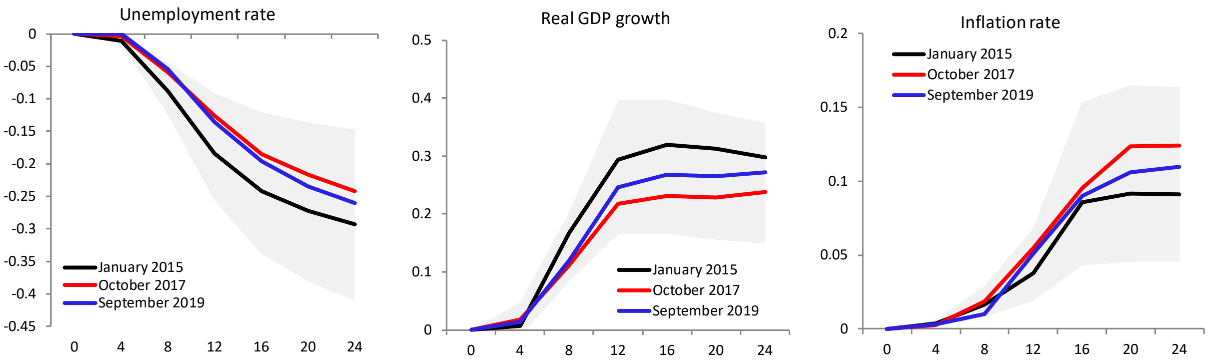
Notes: Model estimated over the whole sample: 1999Q1 to 2019Q4. Black solid lines denote the conditioning paths, i.e. the estimated cumulated effect of QE on policy variables as reported in Figure 8. Blue lines denote the impact of QE on macroeconomic variables and other variables. All variables (including conditioning rate variables) are expressed in deviation from baseline. Real GDP growth, inflation rate, loan to firms and loan to households are expressed in annual changes; in percentage points.

Figure 12.1: Impact of three 10bp NIRP actions



Notes: The analysis is based on a BVAR model with 17 variables and a dense, controlled event-study approach to identification. Figure 11.1 is generated using a calibrated version of the model whose coefficients are estimated over the whole sample: 1999Q1 to 2019Q4. Figure 11.2 is generated using different calibrated versions of the model: the black line using data up to 2014Q2; the red line using data up to 2015Q4; the blue line using data up to 2019Q2. The shaded area reflects the dispersion of the median responses obtained over the simulation samples.

Figure 12.2: Impact of three €500 billion increases in purchases



Notes: The analysis is based on a BVAR model with 17 variables and a dense, controlled event-study approach to identification. Figure 13.1 is generated using a calibrated version of the model whose coefficients are estimated over the whole sample: 1999Q1 to 2019Q4. Figure 13.2 is generated using different calibrated versions of the model: the black line using data up to 2014Q4; the red line using data up to 2017Q3; the blue line using data up to 2019Q2. The shaded area reflects the dispersion of the median responses obtained over the simulation samples.

6. Robustness

This Section of the paper is devoted to robustness analysis. We start by challenging our approach to quantifying the contribution of NIRP as a standalone policy instrument to the configuration of interest rates and cross-check our results with an approach based on a shadow-rate term structure model. We then document the results of an iterative procedure aimed at addressing questions about the way we translate the *no*-NIRP rate scenario into a counterfactual macroeconomic trajectory

Is a shadow-rate model approach a preferable alternative?

We think few considerations underpin our answer to the question in the sub-title, which is a qualified no. Essentially, within a shadow-rate model[39] the effective lower bound often turns out to act as an "all-absorbing state", soaking up – over short horizons – the bulk of the predictive density mass for rate expectations that the model projects forward from any point in time. To be sure, this characteristic explains part of the shadow-rate model's success in forecasting future realisations of the short rate over short horizons, when rate histories evolve along paths that consistently remain close to the effective lower bound. Indeed, in those conditions, short-term interest rates are greatly constrained in their movements near the lower bound, so compressed predictive volatilities, such as those that one obtains from a shadow-rate model, help predict the future level and realised variance of interest rates fairly well. If one is interested in producing superior rate forecasts a few steps ahead, a shadow-rate framework exhibiting this property is very attractive. However, our perspective here is very different. We are interested in quantifying the contribution of NIRP to the conditional distribution of future interest rates. For us, the relevant performance metric is not a forecast error, but whether the point-in-time, say, twelve-month-ahead conditional predictive distribution of the overnight rate conforms more or less precisely with the contemporary risk-neutral rate outlook entertained by investors over the same horizon. While there is no undisputed protocol on how to judge the plausibility of model-generated predictive rate densities, we believe that option-based statistics of rate expectations set a cogent standard against which time-series model inference can be appraised. By that standard, it is legitimate to query the empirical fit of the densities implied by shadow-rate models: their model-implied rate densities are constrained in shape by construction (as they arise as censored versions of homoscedastic normal distributions). In particular, the shadow-rate-model implied distributions can become greatly squeezed (at times, degenerate) and thus fail to reproduce the rate uncertainty that investors express in rate option contracts even after a long time in which the policy rate has been kept invariant at levels close to its lower bound. [40]

[39] Shadow rate term structure models (SRTSMs) as most commonly applied in the literature are a variant of affine (linear) Gaussian term structure models, with the additional property that interest rates cannot fall below an effective lower bound (ELB). The key ingredient of SRTSMs is a "shadow rate" that is driven by a number of factors, which in turn follow a linear VAR with homoscedastic Gaussian innovations. The shadow rate can assume any positive or negative realisation, and conditional predictive shadow rate densities are Gaussian. The actual short-term rate is given as max(shadow rate, ELB). Short rate realisations are hence bounded from below by the ELB, and its predictive densities are not normal but censored normal: there is a (discrete) probability mass of the short rate sticking to the ELB and a standard density part governing rate outcomes above it.

[40] More specifically, there are three features of the most commonly used shadow rate models that give rise to their reduced flexibility in generating implied future short-term rate distributions. First, the underlying factor process driving the shadow rate has homoscedastic innovations, hence ruling out time variation in the uncertainty regarding future shadow rates. Second, the future (say, 12 months ahead) short-term rate distribution arises from the Gaussian shadow rate distribution by truncating the latter at the effective lower bound. Especially for the euro area, characterised by uncertainty about the level of the lower bound itself, a censored normal distribution is probably a too rigid description of future short-term rate densities. In particular, the occasionally distinct probabilities assigned to levels below the actual forward rates, as suggested by options, are not replicable by those models. Third, shadow-rate models often estimate the level of the current and expected shadow rate to be deeply negative, so that the

Figure 13 contrasts the predictive risk-neutral rate densities that one obtains from rate options (left column) and from the shadow-rate model estimated by Lemke and Vladu (2017, right column), corresponding to end-June 2013 and end-July 2015 (upper and lower row, respectively). For the shadow-rate model, we report the implied symmetric Gaussian shadow-rate distributions, whose portions above (below) the estimated lower bound of the time is marked as blue (green). Said differently, the blue area is the predictive distribution of the short-term rate, censored at what is the *pro tempore* lower bound. The asymmetry of the short-rate distribution implies that the mean of the distribution (the black line, i.e. the forward curve) is above the median (blue solid line).

While the options-based and model-implied short-rate distributions corresponding to end-June 2013 (top row on Figure 13) are relatively similar, those corresponding to end-July 2015 (bottom row) differ materially. While the views about the likely path of the policy rate that are embedded in the rate options retain a certain dispersion well into the unconventional policy era (see the significant probability mass assigned to both sides of the forward curve by the distribution on the left column), the short-rate distribution produced by the shadow-rate model is entirely degenerate at the estimated effective lower bound through an 18-month horizon. We therefore conclude that the shadow-rate model is probably too inflexible for conducting the sort of counterfactual no-NIRP simulations that we consider interesting.

All this being said, it is a worthwhile exercise to gauge the extent to which our results deviate from those that could be obtained from a standard shadow-rate model. For this purpose, we utilise the model of Lemke and Vladu (2017) to generate an alternative "*no*-NIRP *with* FG" scenario through the following steps. For each month between summer 2014 and October 2020, we extract from the Lemke-Vladu model the risk-neutral shadow-rate densities stretching through an 18-month horizon. The obtained densities are always censored normal distributions, with their censoring points becoming (more) negative over time as the model features a time-varying effective lower bound. The mean of that distribution is the model-implied forward rate for the respective horizon. We then construct counterfactual short-rate distributions by keeping the model-implied shadow-rate distributions fixed, but imposing ZLB throughout. The associated short-rate densities are again censored normal distributions, but this time with a censoring point set uniformly equal to the ZLB, and hence with a higher implied mean, the counterfactual forward rate.

Figure 14 compares the time series of NIRP impacts on the forward rate that we obtain from the shadow-rate model procedure just described with the outcome of our preferred options-based methodology expounded in Section 4. The left panel runs the comparison for the 12-month ahead forward rate, while the right panel does the same for the 18-month forward rate. Reassuringly, the two impact series show very similar dynamics. At the same time, the shadow-rate model-based estimated

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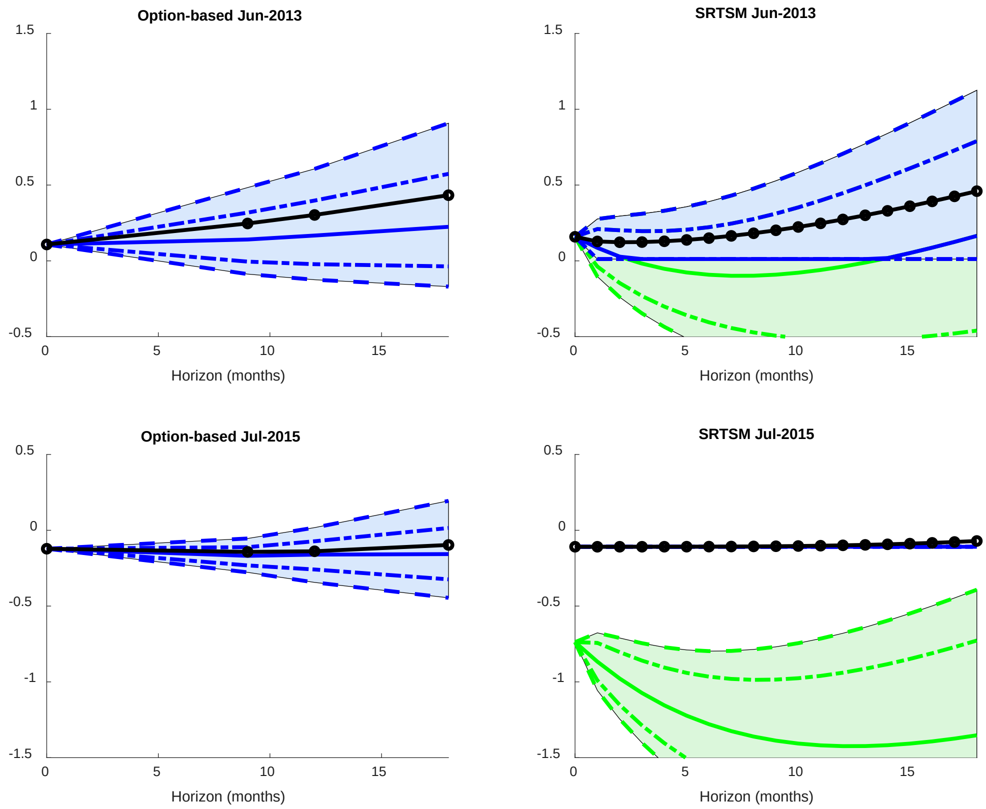
surrounding shadow rate distribution is significantly below the lower bound and the implied short-rate distribution sees very little (and less than as suggested by options) probability for rate outcomes above the lower bound.

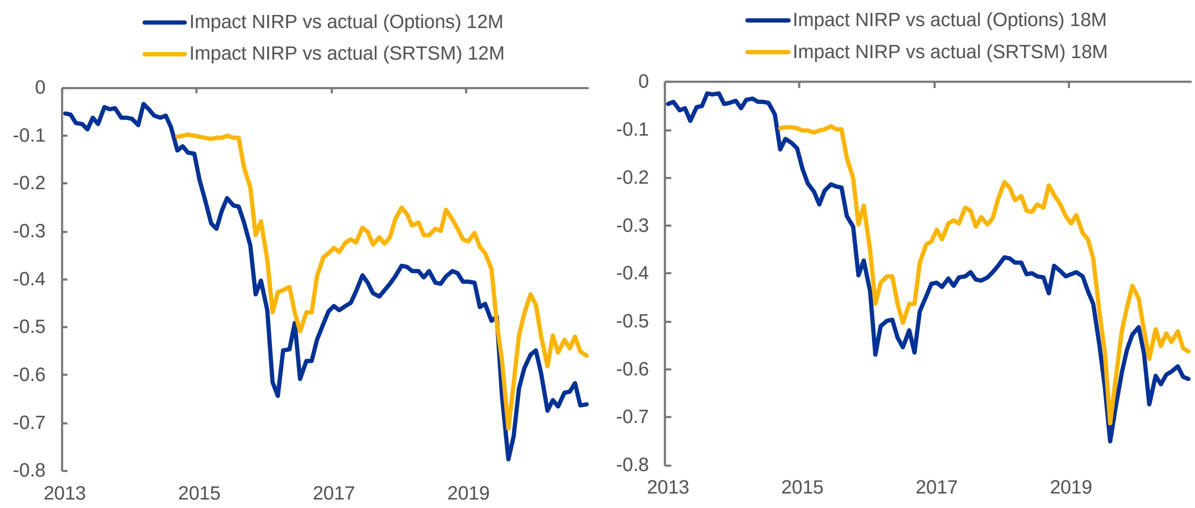
impacts are smaller. The main reason for this is to be found in the specific model features discussed before. When the shadow rate density falls into a deeply negative region, then the counterfactual distribution censored at the ZLB is degenerate at zero. Hence the model-implied impact is essentially the difference between the original forward rate and zero. The options-based approach, by contrast, produces densities that typically retain some probability mass below zero (see Section 4). Therefore, re-apportioning that probability mass to zero gives rise to an additional "bias" for the counterfactual forward rate, which in turn amplifies the estimated NIRP impacts.

Figure 13: Option-implied vs. shadow rate model-implied predictive densities of future 3-month rates *(percent)*



Notes: Rows: Predictive densities of future short-term (1M/3M) OIS rates at 30 June 2013 and 31 July 2015. First column: Fan chart based on option-implied (3M Euribor futures options) densities for horizons of 9M, 12M and 18M using ECB estimates. Translation from Euribor to OIS space by subtracting respective Euribor-OIS spread (spot and forward). The black line is the forward curve (risk-neutral mean), the blue dashed lines represent the 15^{th} and 85^{th} percentiles, the blue dashed-dotted lines are the 25^{th} and 75^{th} percentiles, and the blue solid line contains the medians. Second column: Blue fan chart based on sequence of risk-neutral predictive densities for 1M OIS based on Lemke/Vladu (2017) shadow-rate term structure model. The black line is the model-implied forward curve (risk-neutral mean). The green fan chart is the sequence of risk-neutral shadow-rate densities. Dashed, dashed-dotted and solid lines with same definition as for the first column. Percentiles of short-rate and shadow-rate densities coincide for magnitudes that are above the lower bound.

Figure 14: Option-implied vs. shadow rate model-implied NIRP impact *(percentage points)*



Notes: Comparison of the impact of NIRP using the option-based approach described in the main part and the approach based on the shadow-rate term structure model (SRTSM). Lines are differences between actual forward rates and the respective no-NIRP counterfactual rates. SRTSM results are based on end-of month data. Option-based results are monthly averages of the daily results for the respective month. Last observation: October 2020.

How credible is our rate/macro counterfactual?

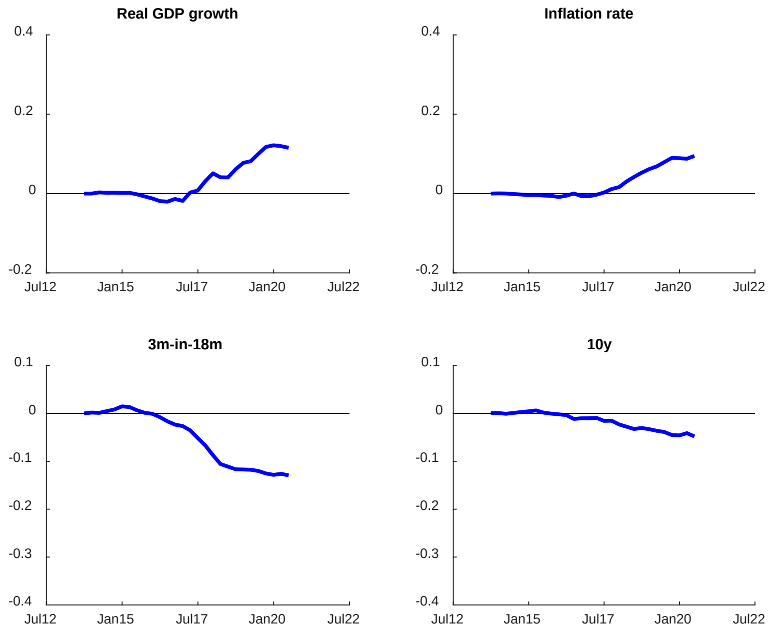
In a nutshell: our rate counterfactuals are more restrictive for the macroeconomy than the rate configuration observed in history. This is the reason why we conclude that the three policies considered in this paper have made a positive contribution to the euro area's macroeconomic performance over the years. But: wouldn't the less favourable macroeconomic outcomes that we associate with our rate counterfactuals have forced an endogenous flattening in the term structure of interest rates? And wouldn't this recursive easing in financial conditions have fed back – in a second round of reaction – onto the macro-economy, and favoured a macroeconomic trajectory less adverse than the one that we imagine would have been associated with the baseline rate counterfactuals that we describe in Section 5? To answer these questions, we start from the counterfactual trajectories of interest rates and the macro-economy that we have discussed in Sections 4 and 5, but now we consider those trajectories only as the first step of a more elaborate iterative procedure. By this procedure, in a second step, we derive the sequence of forward curves and sovereign yield curves that the model considers would most likely correlate with the step-one counterfactual macroeconomic trajectory (the *no*-NIRP and *no*-QE scenarios of Section 5). Specifically, we condition on the trajectory of GDP growth, unemployment, inflation and loan growth we have derived in the first step, and on the Eonia remaining constant at the ZLB, and assume that the 3-month forward rate 12 and 18 months ahead and sovereign bond yields with maturities of 2-, 5-, and 10-years adjust endogenously, reflecting the estimated regularities on the association between rates and the underlying macro-economy that are embedded in the model. . In a third step, we feed the model with this new sequence of forward curves and sovereign yields generated in the second step, and we apply the same identification approach for monetary policy interventions we have used in the first step and expounded in Section 4. This gives rise to yet a new macro-economic trajectory. We then evaluate the extent to which the third-step rate and macroeconomic trajectories differ from the baseline rate and macroeconomic counterfactuals of Sections 4 and 5. A wide difference would signal that the impacts illustrated in Figures 12.1, 12.2 and 12.3 might be overstated.

In Figure 15 we plot the gaps between the quantitative impacts of NIRP (four upper panels) and QE (four lower panels) on GDP growth, inflation, the forward rate and the 10-year yield that we derive from the iterative procedure laid out above and those that we obtain for the two policies from the baseline one-step procedure behind Figures 12.1 and 12.3. The gaps for growth and inflation are a measure of the potential bias amplifying the estimated efficacy of the two policies according to the baseline methodology proposed in Section 5. As is apparent in the pictures, the bias for both growth and inflation is indeed positive, although for both policies well within the confidence band around our baseline impact statistics (see the dashed lines around the growth and inflation baseline impacts in Figures 12.1 and 12.3). Shall we nevertheless conclude that our central NIRP and QE impact estimates entail, by the end of our sample, an upward bias of the order of 0.1-0.2pp for activity and inflation? To answer, notice how the model recursively engineers the "endogenous easing" of financial conditions that one assumes would have occurred if policy inaction had let the economy deteriorate to the extent reflected in our baseline counterfactual. It is particularly interesting to see that the weak economy and the very subdued inflation readings foreseen in our baseline macroeconomic counterfactual would not have been enough to push down yields at the back end of the sovereign curve (see the modest negative gap between the 10-year yield projections in the two scenarios). In all likelihood, this is due to the ambiguous effect a "bad economy" typically exerts on the long end of the average sovereign curve in the euro area: pulling down the term premium, but increasing the credit risk premium paid on the sovereign bonds issued by the euro area's periphery (see, among others, De Grauwe and Ji (2013), ECB (2014), Kim et al. (2015), Paniagua et al. (2016), Afonso and Jalles (2019)). The "endogenous easing", rather, comes almost entirely through a sharp inversion of the forward curve over its short- to medium-maturity segment (see the measurable negative gap shown in the forward rate panel, and recall that the Eonia is pegged at zero in the policy-inaction scenario). In fact, according to the iterative procedure, the 12-month-in-18-month forward rate would have declined to -0.20 percent by end-2018 and -0.3 percent by end-2019 in the absence of NIRP and QE, approaching by the latter date the level it did attain in history (-0.4 percent), after a long period spent under NIRP.

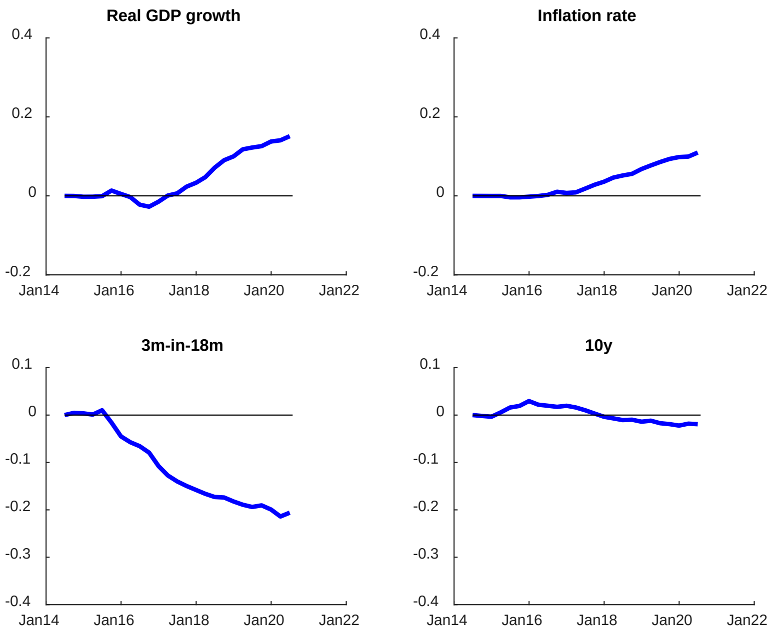
Would this plunge in the forward rate have been conceivable in a genuine policy-inaction scenario in which the ECB had remained staunchly faithful to a ZLB strategy? A reasonable guess is that, given the tight linkage between movements in that portion of the forward curve and the reaction function that – markets figure – governs the policy rate, it would have taken a pronounced change in the ECB's FG about the future direction of its policy rate, and in particular entrenched expectations of an aggressive NIRP policy being adopted in the near future, for this inversion to be emerge and last for so long. But we consider this occurrence as very unlikely, as those expectations would have been continuously and systematically falsified in a genuine policy-inaction world. These considerations, we believe, lend credence to our single-step counterfactual scenario procedure, on the basis of which we have generated the impact results shown in Figures 12.1, 12.2 and 12.3.

Figure 15: Differences in macroeconomic impact of NIRP and QE from an iterative procedure

Negative interest rate policy



Quantitative Easing



Note: Model estimated over the whole sample: 1999Q1 to 2019Q4. Real GDP growth, inflation rate, loan to firms and loan to households are expressed in annual changes; in percentage points. The solid lines are the differences between the impact obtained from our baseline impact analysis as documented in Figure 11.1 and 11.3. and a counterfactual analysis that uses an iterative procedure to purge the endogenous reaction of the yield curve following a macroeconomic deterioration that would have materialized in absence of a policy intervention from the estimated policy-induced reaction in yields.

7. Conclusions

NIRP appears a mere extension of the conventional rate policy to a shallow area below zero, but it is not. When NIRP is in place it is harder for the econometrician to tell its effects apart from those associated with FG and QE, because it transmits through financial prices in a similar way. Because of this commonality, NIRP can empower an easing strategy based on FG and QE to fight recessions and rapid disinflation when interest rates are already low to start with. We put forward a methodology to identify NIRP as a standalone instrument, using the rate expectations embedded in rate options. We find that the three policies combined have had significant expansionary effects on the euro area macro-economy, with real activity, credit, financial prices and inflation all rising and unemployment declining notably as a result of their application.

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