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ASSESSING THE IMPACT OF UNCONVENTIONAL MONETARY POLICY ON LONG-TERM INTEREST RATES IN THE EURO AREA WITH THE USE OF A MACRO-FINANCE MODEL

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ABSTRACT

This paper draws on the macro-finance model developed in Brissimis and Georgiou (2022) which exploits the expectations hypothesis with time variation in the term premium, to evaluate the effects of unconventional monetary policy on long-term interest rates in the euro area. The empirical specification of the model provides an overall excellent fit to the data of the euro area. To assess the effects of quantitative easing, we employ stock measures of this variable derived from the liabilities side of the Eurosystem balance sheet. We provide estimates for both short-run and long-run effects, the latter resulting from sustained increases in central bank liabilities. Our empirical results suggest that stronger effects on long-term rates arise from broader measures of quantitative easing, although these effects seem to have weakened during the negative interest rate period.

JEL classification: E43, E44, E52, E58

Keywords: Quantitative easing, expectations hypothesis, term premium, central bank liabilities, base money, reserves

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1. Introduction

Unconventional monetary policies that were deployed by the Eurosystem and other major central banks since the global financial crisis, led to significant expansions of central bank balance sheets and have remained since then, part of the central bank set of instruments to ensure price stability. In the presence of an effective lower bound on short-term interest rates, the aim of these policies has been to strengthen the transmission of monetary policy and affect the long end of the term structure thus providing monetary stimulus to the economy.

Motivated by the implementation of monetary policy in the presence of a zero lower bound of the short-term interest rate, we turn to the model developed in Brissimis and Georgiou (2022) −that has already been applied to the US− to study the link between the long-term interest rate and the conduct of monetary policy in the euro area. The model has been the first to exploit the Expectations Hypothesis (EH) according to which the long-term interest rate is determined by expectations about future short-term interest rates but also by a term premium which is varying over time mainly under the impact of unconventional monetary policy.[1] Specifically, the model: (i) incorporates a conventional monetary policy interest rate rule for the expectations path of future short-term rates, effectively providing the link between long-term interest rates and the macroeconomy, and (ii) interprets the term premium component in terms of two driving forces, financial uncertainty and unconventional monetary policy as reflected in the central bank balance sheet; this latter effect is the focus of this study.

The literature on the impact of unconventional policies, such as quantitative easing, on long-term interest rates mainly discusses two main transmission channels, namely (i) a portfolio rebalancing channel driven by permanent reductions in the relative supply of financial assets available to the private sector (Tobin, 1969; Modigliani and Sutch, 1966; Andrés et al., 2004; Vayanos and Vila, 2009/2021) and (ii) the signaling channel driven by the signal provided by central bank communication regarding its future intentions to affect short rate expectations (Krugman, 1998;

[1] In the context of the EH, earlier papers that have accounted for time variation in the term premium, described this premium empirically as an exogenous autoregressive disturbance term (McCallum, 1994), as varying through the dependence of its variance on the variance of the expected change in interest rates (Dotsey and Otrok, 1995), as driven by a single factor correlated to the term spread (Tzavalis and Wickens, 1997; Harris, 2001) or as a serially uncorrelated stochastic term (Ruge-Murcia, 2006).

Eggertsson and Woodford, 2003). More recently, a few papers discuss separately reserve-induced (rather than bond supply-induced) portfolio rebalancing effects on long-term interest rates which are tied to the increase in central bank reserves per se as a possible driver of the declines in long-term interest rates (Christensen and Krogstrup, 2018; Arrata et al., 2020; Ryan and Whelan, 2021).

So far, affine models that have been extensively employed in the literature to study yields across the maturity spectrum have used yield curve or latent yield curve variables as factors, providing overall a very close fit to the data (Ang and Piazzesi, 2003). The addition of macroeconomic or securities supply variables in these models to explain yields through the term premium component (Li and Wei, 2013; Ihrig et al., 2018; Eser et al., 2019), has improved their economic interpretation but still leaves the main relationships between yields, the term premia, and factors rather ad hoc.

To assess the effects of unconventional monetary easing on bond yields in the euro area, we employ alternative liquidity measures from the liabilities' side of the Eurosystem balance sheet, namely base money, banks' current account reserves with the Eurosystem plus currency in circulation, or solely banks' current account reserves with the Eurosystem. Although the identification of separate channels of transmission of unconventional monetary policy is not the aim of this paper, measures from the liabilities side of the central bank balance sheet could be more relevant in the case of the euro area than in the US, as unconventional policies applied by the Eurosystem comprised both large scale asset purchases as well as increased long-term lending operations to euro area banks due to the higher bank-based financing of the domestic economy; asset purchases on the other hand, have been a more central element of the unconventional policies followed by the Fed. These balance sheet variables address stock effects of the central bank policy (rather than flow effects) as they capture not only ongoing operations and purchases but also the evolution of stocks in terms of their reinvestment, expiration, etc. The adopted framework explicitly recognizes in its dynamics the important role of macroeconomic trends as well as the high degree of persistence in interest rates, allowing to disentangle short-run and long-run effects of quantitative easing on bond yields that further enhance our insight in the adjustment of long-term interest rates to equilibrium.

Based on the above macro-finance framework, our paper examines the behavior of long-term interest rates in the euro area using quarterly data for the period 1999-

2019. This period comprises the first years of the EMU, the euro cash changeover, the 2005-2007 bond yield conundrum, the global financial crisis and the sovereign debt crisis as well as the persistently deflationary environment that followed. From a monetary policy perspective, it covers the period of conventional interest rate policy adjustments prior to the global financial crisis, a subsequent period of moderate central bank balance sheet expansion (conducted mainly through a fully elastic provision of liquidity to banks) up to mid-2014, the period of massive balance sheet expansion mainly on account of the public sector asset purchases lasting up to end-2018, and a last period of short duration during 2019 when the Eurosystem proceeded only with re-investments before resuming asset purchases at a low pace at end-2019.

We show that the EH with variation in the term premium can be effectively employed to analyze the behavior of the long-term interest rate, apart from the US, also in the case of the euro area. Inflation and the output gap are effectively factored into the expectations path of future short-term rates along with a declining path in the real equilibrium interest rate. In addition to the effects of uncertainty on financial markets, we find substantial negative effects of unconventional monetary easing on bond yields; according to our estimates, a one-unit rise in the corresponding ratio of quantitative easing −measured by base money, banks' current account reserves with the Eurosystem plus currency in circulation, or solely banks' current account reserves with the Eurosystem, all scaled by GDP− should reduce the euro area 10-year government bond yield by 69, 75 or 29 basis points respectively; if the increase is sustained in the long run, it is estimated that the decline would reach up to 257, 300 or 156 basis points in each case.

The remainder of the paper is structured as follows. Section 2 reviews unconventional monetary policy measures of the Eurosystem during the period examined. Section 3 summarizes the available literature with empirical results for the euro area. Section 4 provides an overview of the theoretical framework. Section 5 focuses on the empirical analysis and discusses estimation results. Section 6 summarizes and concludes.

2. The Eurosystem unconventional monetary policy measures

In the course of the lifetime of the euro since 1999, the conduct of monetary policy in the euro area underwent significant changes in parallel with changing macroeconomic and financial conditions. The severe financial crisis of 2008-2009 and the sovereign debt crisis that ensued, brought about serious repercussions for the real economy in the euro area and complicated the assessment of risks to price stability as well as the way in which monetary policy could attain its primary objective. In this context, maintaining price stability and the need to prevent disinflationary conditions from settling down in the euro area required both a rapid lowering of the key policy rates by the Eurosystem as well as gradually adopting unconventional (non-standard) monetary policy measures that entailed a significant expansion of the Eurosystem balance sheet with substantial modifications in the operational framework of monetary policy.[2] Initially, unconventional measures were temporary and limited in size, but since the second half of 2014, after short-term rates had become negative and were effectively approaching a lower bound, they became essential policy tools for responding to persistent deflationary conditions.

The unconventional measures of the Eurosystem comprised: (i) use of broader frameworks for liquidity provision to banks; (ii) central bank asset purchases that were intensified after 2014, when the scope for further interest rate cuts had been significantly reduced; (iii) forward guidance on the future path of interest rates and (iv) a negative interest rate policy implemented since mid-2014, challenging the view that short-term rates cannot fall further below zero.

Up to the global financial crisis (2007-2008), the Eurosystem had been steering short-term money market rates toward the middle of the corridor defined by the interest rates in the two overnight standing facilities of the Eurosystem,[3] i.e., close to the Eurosystem's main refinancing operations rate (MRO) (Figure 1), and the operational framework was designed to operate under scarce liquidity conditions. Following the onset of the global financial crisis, it became necessary for the Eurosystem to provide increased liquidity to the banking system thus pushing short-term interest rates downward, from the MRO rate toward the lower end of the interest rate corridor, i.e.,

[2] See Rostagno et al. (2019) and Aberg et al. (2021).

[3] Specifically, short-term rates in the money market were steered toward a level in between the deposit facility rate (DFR) and the rate of the marginal lending facility (MLF) of the Eurosystem, which determined respectively, the lower and upper bound of the interest rate corridor.

close to the deposit facility rate (DFR) (Figure 1). Since the start of the expanded asset purchase programme (APP) in 2015, the operational framework of the Eurosystem has essentially been operating under a floor system, in which the central bank systematically provided large amounts of excess liquidity to the banking system.

[Insert Figure 1 here]

Right after the eruption of the global financial crisis in August 2007, the Eurosystem started to lengthen the maturity composition of its refinancing operations, while in April 2008 it also started to offer supplementary 6-month refinancing operations and, later on, special-term refinancing operations (Table 1). Following the collapse of Lehman Brothers in September 2008, the Eurosystem adopted a package of "enhanced credit support" measures. In this context, it modified the conduct of the main and longer-term refinancing operations to ensure a fully elastic supply of liquidity to counterparties, with a fixed rate full-allotment procedure (FRFA) that is being maintained until today.[4] At the same time, it also prolonged further the maturity of available operations with the introduction of three one-year LTROs (Table 1). Since end-2008, unconventional measures resulted in a progressive and significant rise of excess reserves in the system and the balance sheet of the Eurosystem started to expand. The monetary base[5] rose by around € 310 billion at end-2008 compared to the end of the previous year while the conduct in December 2011 and February 2012 of further two three-year long-term refinancing operations resulted in liquidity provision of over € 1 trillion to the banking system.

[Insert Table 1 here]

In May 2009, the new framework of liquidity provision was complemented with the first covered bond purchase programme (CBPP1) aiming to revive the market of covered bonds that constituted an important funding source for banks, but its operation had been severely disrupted since autumn 2008. This was the first of a series of initial asset purchase programmes by the Eurosystem that were conducted due to acute financial market tensions and were considered to be temporary in nature.

[4] The provision of abundant liquidity was accompanied by broadening the pool of eligible securities accepted as collateral as well as by swap agreements with other major central banks for foreign currency liquidity provision, mainly in US dollars with full allotment and at various maturities.

[5] In the euro area, base money consists of banknotes in circulation, the deposits that credit institutions hold as minimum reserve requirements, their excess reserves and the recourse to the deposit facility (ECB, 2017).

The financial crisis brought about a major impact on euro area sovereign bond markets that was particularly intense for the countries of the monetary union with high public debt, some of which had to adopt an economic adjustment programme. In May 2010, the first programme of outright secondary market purchases of government bonds, the Securities Market Programme (SMP), was introduced with a view to ensuring the depth and liquidity in national government bond markets that had been malfunctioning, thus threatening the smooth transmission of monetary policy. As the programme was intended to be of a temporary nature and did not aim to affect the stance of monetary policy, excess liquidity created in the context of this programme was absorbed on a weekly basis through specific fine-tuning liquidity absorbing operations. In November 2011, due to intensified financial market tensions, the Eurosystem launched a new covered bond purchase programme (CBPP2) to ease euro area banks constraints on the liquidity side; the CBPP2 was of a pre-defined intended amount of covered bond purchases in the primary and secondary markets.

Since mid-2011, the debt crisis had intensified because of the feedback loop between banks and sovereigns in some euro area countries and this was evidenced by the strong fragmentation of bond markets. These acute market pressures in sovereign bond markets contributed to a marked deterioration in economic conditions and the emergence of redenomination risks in the euro area resulting in a second round of Eurosystem interventions under the SMP.

Despite the conduct of the Securities Market Programme, redenomination risks in the euro area persisted. The announcement of the establishment of Outright Monetary Transactions (OMTs) from the President of the ECB in August 2012, in the context of which the Eurosystem could purchase, with appropriate conditionality, bonds of individual euro area member countries following an economic adjustment programme, communicated with credibility the commitment of the Eurosystem to encounter such risks. The OMT programme has, in practice, never been activated, but the mere announcement of its establishment contributed decisively to removing redenomination risks in the euro area and had a positive impact on financing conditions, significantly containing uncertainty; thus, in mid-2012 the Eurosystem balance sheet started to slowly contract (Figure 2).

[Insert Figure 2 here]

However, in view of aggravating deflationary pressures in the course of 2013 and 2014 and as policy rates were approaching effectively their lower bound, the Eurosystem decided to have recourse to non-standard purchases of assets under its asset purchase programme (APP) to add further monetary stimulus to the economy (Table 2). During this period, a central feature of non-standard refinancing operations has been the use of targeted longer-term refinancing operations (TLTROs). These operations, conducted in three rounds with a start from September 2014, involved the provision of liquidity at very favourable terms, i.e., at a zero or even negative interest rate, under the condition that banks benefiting from these loans should provide adequate new business or consumer loans to the economy (Table 1).

In the same context, the third covered bond purchase programme (CBPP3), initiated in October 2014, included purchases of euro-denominated eligible covered bonds both in the primary and secondary markets, while the asset-backed securities purchase programme (ABSPP) launched in November 2014, aimed at the purchase of simple and transparent ABS issued by the private sector also on the primary and secondary markets.

[Insert Table 2 here]

In January 2015, the Eurosystem expanded its asset purchases by adding a public sector purchase programme (PSPP) for the purchase of bonds issued by euro area central governments, agencies and European institutions or regional and local governments in the secondary market; up until 2019, the PSPP accounted for the bulk of Eurosystem asset purchases. In March 2016, a corporate bond purchase programme (CSPP) was also added to the APP to include purchases of investment-grade euro-denominated bonds issued by non-bank corporations.[6] As macroeconomic conditions evolved, the pace of purchases under the APP was adjusted accordingly, while the Eurosystem had been reinvesting (in full) the principal payments of maturing securities purchased under the APP since December 2015. Net asset purchases continued up to end-2018, while during 2019Q1-2019Q3 the Eurosystem made only re-investments in maturing securities holdings.

[6] At end-2019, total Eurosystem asset holdings under the APP amounted to € 2.6 trillion; the PSPP represented 82% of these holdings, the CBPP3 10%, the CSPP 7% and the ABSPP 1% respectively.

As a result of the Eurosystem's various non-standard refinancing operations and asset purchase programs, the monetary base, and the quantity of excess reserves, rose dramatically on the liabilities' side of its balance sheet (Figure 2). While required reserves grew rather modestly and since 2012 were actually reduced, excess reserves rose continuously during 2008-2019 from €1 billion in the second quarter of 2008, to around € 105 billion in the third quarter of 2014, just before the start of the APP, and further to €1.5 trillion at end-2019. The monetary base increased respectively from €880 billion in the second quarter of 2008 to around € 1.2 trillion in the third quarter of 2014, and to an unprecedented level of €3.2 trillion at end-2019.

3. Review of the effects of unconventional monetary policy in the euro area

The literature on the impact of unconventional monetary policies, such as quantitative easing, on financial markets in the euro area has been mostly based on the event study approach. This approach builds on the forward-looking nature of financial markets under the assumption that asset prices incorporate immediately any news on policy changes announced by the central bank. By employing high-frequency data at a sufficiently narrow window of time around policy announcements, event studies aim to tackle issues of endogeneity between monetary policy and asset prices. However, because of their focus on a narrow window of time and other weaknesses related to the use of market expectations, the above studies estimate immediate effects of policy announcements but can hardly address any persistence of effects or potential reversal of them.

Several event-study analyses (see among others Beirne et al. (2011), Falagiarda and Reitz (2015), Szczerbowicz (2015), Altavilla, Giannone and Lenza (2016), Jäger and Grigoriadis (2017) and Krishnamurthy et al. (2018)) focused on the earlier phases of ECB's unconventional monetary policy, including the SMP, OMT, CBPP1 and CBPP2 and LTROs programmes. They overall conclude that ECB announcements contributed to reducing bond yields or spreads, most prominently in the vulnerable periphery euro area countries. Subsequently, other event studies provided evidence on announcement effects of the expanded asset purchase programme of the Eurosystem (APP) initiated at end-2014. Andrade et al. (2016), Bulligan and Monache (2018) and

Urbschat and Watzka (2020) found sizeable reductions in long-term government bond yields as a result of announcements of the public sector purchase programme (PSPP), while also indicating that these effects were most pronounced at the initial announcement of the programme.[7] Recent event studies have elaborated on the construction of measures of market expectations for quantitative easing. Altavilla et al. (2019) constructed a detailed monetary policy event-study database for the euro area on ECB policy communication and information flow on yield curve changes while, in a panel error correction framework, De Santis (2020) utilized the discussion intensity in the media to identify expectations about the ECB's quantitative easing. Both studies suggest that the APP has been effective in easing financing conditions, suggesting some persistence of effects over time. Based on security-level data, Altavilla et al. (2021) constructed empirical proxies for separate channels of quantitative easing (local supply, duration risk and credit risk)[8] while Arrata and Nguyen (2017) studied local supply effects of the ECB's PSPP on the French bond market.

Other authors employ term structure or VAR models to trace the impact of ECB's APP on sovereign bond yields. The identifying assumption in these models is that the variables for the supply of assets of different maturities are considered to be exogenous with respect to the term premium, suggesting that neither the Treasury nor the central bank would adjust the supply of assets in response to changes in the term premium (Kuttner, 2018). Eser et al. (2019) deploy an affine term structure model similar to that of Li and Wei (2013), in which on top of the level and slope yield curve factors, the link between bond supply and the term premium is captured by a quantitative measure of duration risk. Based on a daily VAR of financial variables and using information on bond price reactions to APP-related announcements as external instruments, Andrade et al. (2016) show that APP effects are quite persistent, while these effects also persistently affect the valuation of other assets. Blattner and Joyce (2020) developed a small macro-finance Bayesian VAR including yield curve and macroeconomic factors and a new measure for the bond free-float and estimated that the ECB's PSPP

[7] Indicatively, Andrade et al., 2016 estimate an effect of 45 bps for the euro area while Bulligan and Monache (2018) estimate a 100 bps decline for the sovereign spread for Italy and Spain and Urbschat and Watzka (2020) reductions in yields ranging from 85.8 bps for Portugal to 5.9 bps for Germany.

[8] They estimate that the APP announcement brought about a reduction in the 10-year bond yield by 61 bps for the euro area, 36 bps for Germany, 45 bps for France, 71 for Italy and that purchases of 10% of GDP reduce by 65 bps the euro area 10-year government bond yield.

significantly reduced euro area 10-year bond yields in 2015 through the duration channel.

Apart from the constant parameter method, a few papers employ time-varying coefficient models to study the determinants of bond yields in several euro area countries. In this context, Afonso and Jalles (2019) found that initial unconventional measures of the Eurosystem had a downward effect on yield spreads, with the CBPP1 effect having a higher magnitude during 2011-2013. Hondroyiannis and Papaoikonomou (2022) attributed coefficient time variation to the variation in perceived risks associated with different fundamental sources of risk, suggesting that the downward impact of APP on yields varies through time and is affected by country-specific conditions.

In contrast to the US, many euro area studies present country-specific effects of unconventional monetary policy in terms of reductions in the credit, liquidity or redenomination risk premium among individual sovereign bond markets with different degrees of creditworthiness (Eser and Scwaab, 2016; Krishnamurthy et al. 2018; Jäger and Grigoriadis, 2017; Fendel and Neugebauer, 2020; Urbschat and Watzka, 2020; Altavilla et al. 2021) rather than signaling or broader portfolio rebalancing effects. In practice only few papers have estimated effects at the euro area level (Altavilla et al., 2021; De Santis, 2020; Eser et al. 2019, Andrade et al., 2016) neglecting the fact that the creation of the monetary union in Europe had been achieved after many years of nominal convergence and increasing financial market integration among member countries. Since then, the conduct of monetary policy entails that a single set of short-term policy rates applies to all euro area countries, while, at the zero lower bound, unconventional policy interventions were aimed at making the euro area monetary policy stance more accommodative rather than targeting securities in specific countries. Thus, the focus on an average euro area government bond yield facilitates assessing monetary policy effects on overall financing conditions and their broader implications for the real economy in the euro area.

Some of the above papers discuss the issue of flow vs. stock effects of quantitative easing. The flow effect supports a rather restrictive view of quantitative easing suggesting that yields should be lower when the central bank is actively buying securities, while such effects could be expected to materialize especially during periods of impaired market function and high financial stress (Altavilla et al. 2021) and pertain more to local supply effects of quantitative easing. Flow effects have been found to be non-statistically significant (Andrade et al. 2016, Arrata and Nguyen, 2017) or sometimes significant but short-lived (De Santis and Holm-Hadulla, 2020).

However, the existence of a broader portfolio-rebalancing channel of quantitative easing and its envisaged effects on the real economy require a sustainable link between long-term interest rates and central bank asset purchases. According to this view, central bank asset purchases permanently reduce the supply, i.e., the stock outstanding, of longer-term bonds (Bernanke, 2022). Permanent reductions in the outstanding amount of longer-term bonds could be the result of the hold-until-maturity and continued reinvestment policies of central banks which sustain a high level of central bank stock of securities. Consequently, it is not flows that matter for yields but rather the total amount of securities that the central bank has accumulated and how long it is expected to hold them (Bernanke, 2022). This discussion relates to the persistence of effects of quantitative easing, i.e., whether they die out soon after announcement or accumulate over time as the size of the central bank portfolio is sustained or grows.

Nevertheless, the literature on how the central bank stock of assets is built up and sustained through time and on how this accumulation interacts with the other elements of monetary policy stance has very recently started to evolve (Coeuré, 2018). In trying to address these issues, Andrade et al. (2016) note that the impact of asset purchases depends on the prevailing market expectations about how asset purchase programmes will be phased out, i.e., whether the central bank's portfolio of securities will be rolled over, or instead quickly liquidated. In the same vein, Eser et al. (2019) provide an assessment of both contemporaneous and dynamic effects of the APP, suggesting that the ensuing term premium compression has been very persistent but fading over time, supporting the view that, the longer the length of the reinvestment period, the larger the impact on the term premium.

Furthermore, studying only bond-supply effects on long-term interest rates provides only part of the information one needs to know for estimating the effects of unconventional monetary policy on long-term interest rates and the broader economy. In the case of the Eurosystem, unconventional central bank lending to banks has also extensively been deployed in the provision of liquidity and the expansion of the central bank balance sheet. Thus, more recently, a few papers also distinguish reserve-induced (rather than bond supply-induced) portfolio rebalancing effects on long-term interest rates which are tied to the increase in central bank reserves per se as a distinct channel of the declines in long-term interest rates (Christensen and Krogstrup, 2018). For the euro area, Ryan and Whelan (2021) examine the behavior of reserves held by banks during the APP of the ECB and suggest that European bond yields declined also as banks actively managed their reserve holdings by purchasing debt securities. Arrata et al. (2020) have also noted that bond scarcity effects in the repo market and other aggregated effects from excess liquidity could account for more long-lasting effects of central bank asset purchases on bond yields.

4. Theoretical framework

The theoretical framework draws on our work on the links between long-term interest rates and the conduct of monetary policy. In Brissimis and Georgiou (2022) we develop a macro-finance model, in which, due to imperfect substitutability between assets, long-term interest rates have both an expectations component (expectations of future short-term rates) and a term premium component which is variable over time.

The model takes a departure from the "strict" expectations hypothesis in which long-term interest rates are determined exclusively by short-term rate expectations, while the term premium is assumed to be zero or constant over time. This departure arises as monetary policy behavior at the zero lower bound can affect the term premium inducing, through unconventional policies such as forward guidance and quantitative easing, further reductions in long-term rates in addition to those implied by the expected path of short-term interest rates. Allowing for the possibility that the term premium is variable over time, the expectations hypothesis may be written as:

$$i_t^n = \frac{1}{n}\sum_{s=0}^{n-1} i_{t+s|t} + tp_t^n \qquad (1)$$

where i_t^n stands for the interest rate of a bond with maturity n, $i_{t+s|t}$ is the expectation of the short-term interest rate s periods ahead conditional on a time t information set, i_t is the one-period current short-term rate and tp_t^n is the term premium (for maturity n) which, in our case, is assumed to vary over time.

In this framework, the expectations component provides, through investors' expectations regarding changes in the short-term interest rate, a link between the long-term rate and the state of the macroeconomy. The short-term rate is determined by macroeconomic variables in the context of a monetary policy reaction function as described by an interest rate feedback rule. This rule, derived as a solution to the intertemporal optimization problem of the central bank, expresses the expectations component of the long-term rate as a function of current economic developments in inflation and the output gap, while the exogenous natural real rate of interest included in the constant term of this rule, has a role to play in the determination of this component.

As far as the term premium component is concerned, standard theoretical finance models suggest that it should depend on interest-rate (short-rate) volatility insofar as this premium is seen as compensation demanded by investors for potential losses stemming from future interest rate movements. [9]

Further, unconventional quantitative easing policy of the central bank should also be taken into account for understanding the term premium component of the long-term interest rate as large-scale asset purchases may affect the term premium through the portfolio rebalancing channel and/or the signaling channel.

By incorporating the determinants of the term premium in terms of interest rate uncertainty and the quantitative easing policy of the central bank, which are varying over time, Brissimis and Georgiou (2022) derive the following model for the long-term interest rate:

$$i_t^n = c_0 + c_1\pi_t + c_2x_t + c_3unc_t + c_4qe_t + u_t \tag{2}$$

where π is the inflation rate, x is the output gap, unc is interest rate uncertainty, qe is a quantitative easing variable and u is an error term capturing macroeconomic or monetary policy shocks.

In the empirical specification of the above model, we explicitly provide for the important role of macroeconomic trends in the dynamics of interest rates. Furthermore,

[9] For investing in a bond of a longer maturity, investors expect returns in excess of the risk-free short-term rate prevailing over the life of the bond. Accordingly, the term premium reflects the riskiness of long-term bonds and the compensation required by investors for that risk. Abstracting from credit and liquidity risk, the most prevalent source of risk for long-term bonds is duration risk, i.e. the sensitivity of the bond price to changes in interest rates.

as it has long been recognized that interest rates exhibit a high degree of persistence, which reflects long-lived effects of fiscal, monetary, preference or technology shocks, interest rate persistence is also taken into account in the short-run dynamics of the model. Thus, the empirical specification of the model takes the following form:

$$i_t^n = c_0 + c_1\pi_t + c_2x_t + c_3unc_t + c_4qe_t + c_5i_{t-1}^n + c_6t + u_t \quad (3)$$

where t is a time trend. In the following section, we utilize the above model that has been applied to study the behavior of the 10-year US Treasury bond yield and the monetary policy of the Fed, to also study the course of long-term rates in the euro area economy with a particular focus on the effects of the ECB unconventional monetary policy.

5. Empirical analysis

5.1 Specification, data and stationarity tests

As already discussed, the model presented above (eqs. 1 to 3) seeks to assess the link between the long-term interest rate and macroeconomic variables (namely inflation, output gap and the equilibrium real interest rate as derived through the expectations path of the future short-term rate). It also examines the importance of the term premium component of the long-term rate in terms of two driving factors, namely market uncertainty and quantitative-easing monetary policy as reflected in the liabilities' side of the central bank balance sheet.

Focusing on the empirical specification of the above model, and as in Monteiro and Vasicek (2019) and Hondroyiannis and Papaoikonomou (2022), we allow the inflation rate and uncertainty to affect the bond yield with some lags so as to mitigate potential contemporaneous feedbacks from the long-term interest rate to these variables.[10] Endogeneity should be less of a concern regarding quantitative easing variables (as captured by the respective monetary base- or reserves-to-GDP ratios), as these policies were not in principle designed to respond to movements in bond prices. On the output gap, the use of several lags[11] helps us overcome the fact that successive observations of the components of this series exhibit a high temporal correlation

[10] The lag length is selected based on using the AIC; as quarterly data are used, the maximum number of lags is set equal to 4 (one year).

[11] For the selection of lags, see footnote 10.

(Gerlach and Smets, 1999). We also allow for the possibility that interest rates are highly persistent as several papers suggest that economic shocks can bring about long-lasting effects on interest rates (e.g., Caporale et al., 2022; Bauer and Rudebusch, 2020). The addition of a linear time trend helps take into account unobserved, trending factors that affect both the long-term interest rate and the explanatory variables. Thus, the empirical model that we will estimate takes the following form:

$$i_t^n = c_0 + c_1\pi_{t-1} + c_{2,1}x_{t-1} + \cdots + c_{2,j}x_{t-j} + c_{3,1}unc_{t-1} + \cdots + c_{3,k}unc_{t-k} + c_4qe_t + c_5 i_{t-1}^n + c_6 t + u_t \quad (4)$$

Figures 3.A-E below provide the diagrammatic representation of the time series data employed in the empirical analysis over the sample period 1999 Q1-2019 Q4, while Tables 3 and 4 summarize the definition of variables and the descriptive statistics of the data. The euro area benchmark government bond yield is plotted in Figure 3.A. The series is a weighted average of the yields (as reported by Refinitiv/Eikon) provided at the ECB data portal for the national government bonds with a residual maturity of around 10 years and reflects euro area changing composition. The weight used for each country is the nominal outstanding amount of the respective bonds for each country to the euro area total. As a weighted average series, the bond yield encompasses possible heterogeneities across bond yields of individual euro area countries stemming (i) from the fragmentation of national bond markets recorded during the sovereign debt crisis, but also (ii) from the margin (of up to two percentage points) that has been allowed by the convergence criterion on long-term interest rates of euro area countries as an entry criterion. The bond yield shows a steady downward trend over the period under examination that becomes more pronounced after the global financial and sovereign debt crises. This protracted declining trend could be associated with the decline in real interest rates that had been recorded in advanced economies for the three decades since the 1980s and has been driven by numerous factors such as declining productivity growth and ageing demographics. In the wake of the global financial crisis, the rise in investor risk aversion and the broader flight to safe assets contributed to an acceleration of this declining trend in real interest rates in the euro area (Brand et al., 2018) before monetary policy became constrained by the effective lower bound of (nominal) interest rates.

[Insert Figures 3.A-E]

Figure 3.B depicts the euro area inflation rate (measured in terms of change in the GDP deflator). Since 1999 and for the first years of the existence of the monetary union, inflation in the euro area was mostly affected by external supply-side shocks that posed significant challenges for the ECB to attain its primary objective of price stability (2%). In effect, during this period, despite the ECB policy rate adjustments, inflation mostly stood above the 2% threshold, as euro area developments in productivity contributed to amplifying the cycle and keeping inflation elevated (Rostagno et al., 2019). However, in the aftermath of the global financial crisis, prior positive supply shocks on inflation were followed by negative demand shocks that gradually formed a disinflationary economic environment during which inflation persistently ranged well below 2%.

[Insert Tables 3 and 4 here]

The output gap estimate for the euro area has been based on AMECO data on the level of annual potential output, which has been interpolated into quarterly frequency using the Litterman method; then the difference of the interpolated potential output level and the real seasonally adjusted GDP series (both in logarithmic transformation) has been taken to arrive at the quarterly estimate of the output gap that was used in empirical estimations. From Figure 3.C, it is evident that the euro area output gap experienced large declines in 2002-2003 and most prominently during the severe recessions associated with the global financial crisis and the sovereign debt crisis. The economic slack in the euro area that resulted from these crises is seen to have closed by the end of 2017, as from end-2014 real output growth consistently outpaced the growth in potential output.

Turning to the term premium component of bond yields, uncertainty surrounding developments in interest rates has been generally recognized as an important factor underlying this component. Amid increased uncertainty about the near-term outlook of the economy or about the future path of interest rates, the information content of longer-term interest rates for monetary policy can be significantly blurred. We proxy market uncertainty using the Composite Indicator of Systemic Stress (CISS index)[12], which is

[12] The CISS is based on standard definitions of systemic risk, while it applies a basic portfolio theory to the aggregation of five market-specific subindices created from a total of 15 individual financial stress measures. It aggregates financial stress at two levels: it first computes five segment-specific stress subindices and then aggregates these five subindices into the final composite stress index. The five subindices are supposed to represent the core of most financial systems: the sector of financial intermediaries, money markets, equity markets (only non-financial corporations), bond markets (government and non-financial corporations) and foreign exchange markets. The aggregation accordingly takes into account the time-varying cross-correlations between the subindices.

a composite indicator of systemic stress in the euro area.[13] The CISS puts relatively more weight on situations in which stress prevails in several market segments at the same time, capturing the idea that financial stress is more disruptive for the economy as a whole if financial instability spreads more widely across the financial system (Holló et al., 2012).

According to the evolution of the CISS index for the period 1999-2019, Figure 3.D shows that its level spiked around several financial crises' episodes such as that after the terrorists' attacks in 2001 but reached unprecedentedly high levels in the 2008 financial crisis and during the sovereign debt crisis in the euro area. Thereafter, except for the period between end-2015 and early-2016, market volatility seems to have averaged at a very low level, as from mid-2013 the ECB started to also use explicit forward guidance on future interest rates to contain interest rate uncertainty and manage to affect the (economically relevant) longer-term interest rates more effectively.

To estimate the effect of the balance sheet policies of the Eurosystem on the long-term interest rate, we employ several alternative definitions of qe from the liabilities side of the Eurosystem balance sheet, all scaled by GDP: (i) base money (qe_1), comprising banknotes in circulation, reserves of credit institutions at the Eurosystem current accounts and the Eurosystem deposit facility, proxying the overall size of the Eurosystem balance sheet, (ii) banknotes in circulation and reserves of credit institutions at the Eurosystem current accounts (qe_2) or (iii) solely reserves of credit institutions at the Eurosystem current accounts (qe_3). These measures reflect the volume of unconventional refinancing operations of the Eurosystem (FRFA, TLTROs etc.) as well as of outright purchases of securities under various Eurosystem purchase programmes. Figure 3.E presents the path followed by these balance sheet variables. They have been recording a mild upward trend since 2002 and up to the start of the financial crisis, incorporating the euro cash changeover in the first years of the monetary union. All three qe variables rise significantly, though temporarily, showing several fluctuations in the aftermath of the 2008 financial crisis, while they start to follow a more persistent and steeper upward path from 2015, after the start of the expanded asset purchase programme of the Eurosystem, and up to 2018 when net asset purchases ended. We did not employ a definition of qe based on Eurosystem securities

[13] As mentioned in Kremer (2016), one should use the square root of the CISS to control for potential non-linearities arising from the quadratic form of the formula with which CISS is computed; this is the volatility-equivalent of this index compared to its published standard variance-equivalent form.

holdings as available data on the securities holdings of the Eurosystem for monetary policy purposes are available only for a limited time period (since July 2009), while a more detailed breakdown per purchase programme (SMP, CBPP1, etc.) is available since 2014.

Next, we explore the stationarity properties of our data series. Table 5A reports the Augmented Dickey-Fuller (ADF) statistic testing the null hypothesis of the presence of a unit root in the variables of our model versus three alternative hypotheses: the variables are (a) stationary, (b) stationary around a constant and (c) stationary around a constant and a linear time trend (trend stationary). Table 5B reports the ADF test results for the variable(s) for which a breakpoint is identified – the quantitative easing variable(s).

[Insert Tables 5A and 5B here]

The results in Table 5A indicate that the long-term interest rate is a strongly trending stationary variable,[14] in line with its diagrammatic representation, showing a downward trend for most of the period under examination. Also, the inflation rate can be assumed to be a stationary variable either with a non-zero mean or with a trend. A similar picture arises for the interest rate uncertainty variable; the results of the unit root tests suggest that this variable is also stationary with a non-zero mean or around a trend. The output gap variable has remained for some time periods below zero and in other above it, while the unit root test results provide evidence that the variable may be stationary with a zero mean.

As far as the alternative quantitative easing variables are concerned, the initial ADF-tests in combination with the visual inspection of figures 3.E, show that in most cases we cannot reject the null hypothesis for the existence of a unit root (Table 5A). However, taking into account the fact that these stock variables increased for some time intervals in 2008-2014 and, more persistently, since 2015, and that conventional unit root tests are biased toward a false unit root null when the data are trend stationary with a structural break, we repeated the ADF test accounting for a breakpoint in the qe series. The test may be computed with a structural break, where the break consists of a level shift (the first two columns in Table 5B), a trend break or both a level shift and a trend break (columns three and four in Table 5B). From these results, it appears that if we

[14] The time period for the unit root test is 1995-2019.

consider the respective breakpoint, the reserves-to-GDP ratio (qe_3) could be assumed to be trend stationary with a breakpoint in the constant, the trend, or both the constant and the trend. In the case of qe_2, the series could be assumed to be trend stationary with a breakpoint in the constant and the trend. The evidence we provide for trend stationarity of the qe_1 series (base money-to-GDP ratio) with a breakpoint is weaker and statistically significant at the 10% level.[15]

5.2 Empirical results

According to the results of the unit root tests, we can assume that each of the euro area data series presents some form of mean-reverting behavior: the long-term interest rate, inflation and uncertainty are assumed to be stationary processes around a trend and the output gap a stationary process with a zero mean. The quantitative easing series appear to be trend stationary with a level shift; the evidence is stronger for the reserves-to-GDP ratio (qe_3) and the reserves and currency-to-GDP-ratio (qe_2) and less so, for the base money-to-GDP ratio (qe_1). We employ the classical linear regression analysis to obtain unbiased coefficient estimates using Ordinary Least Squares. A linear time trend has been added in our specification, interacting with a dummy variable for the period 2011Q2-2016Q3 during which euro area bond yields had been mostly driven by domestic idiosyncratic factors due to the repercussions of the sovereign debt crisis. The errors are assumed to be independently and identically distributed following the normal distribution. We also use robust (HAC) standard errors to account for heteroscedasticity and autocorrelation in the error term that could render the conventional OLS standard errors and statistics inappropriate.

Table 6 reports the results of OLS estimations. Columns (1)-(3) differ with respect to the alternative definition of the unconventional monetary policy variable employed each time (qe_1, qe_2, qe_3), each standing for a different subtotal of the liabilities side of the central bank balance sheet (base money-, or reserves and banknotes-, or reserves-to-GDP ratio, respectively). All estimations generate statistically significant coefficients for the main variables with the expected sign. The results of the Breusch-

[15] This could be related to the fact that qe_1, apart from current account reserves and banknotes in circulation, also includes the deposit facility component, which paid a positive remuneration to banks compared to reserves for most of the period under examination, which, combined with other bank balance sheet and liquidity considerations could make the series less strongly stationary.

Godfrey LM test of 1st to 3rd order autocorrelation show that there is no autocorrelation in the error term. The residuals of equations (1), (2), (3) appear to be stationary, as evident from their diagrammatic representation and confirmed by the respective unit root tests. As Figure 4 shows, our model provides an excellent fit to the data.[16]

[Insert Figure 4 here]

As already discussed, the persistence of the effects of various economic shocks on interest rates is captured by the lagged dependent variable i_{t-1}. Its autoregressive coefficient (which is equal to 1-δ, where δ is the speed of adjustment within one quarter) is highly significant in all cases ranging between 0.73 and 0.81. These values imply a relatively slow adjustment of the interest rate to the long-term mean; it is estimated that deviations of the long-term rate from equilibrium are corrected by one-fourth to one-fifth of the deviation per quarter. Interest rate adjustment is estimated to be relatively faster in equations (2) and (1) involving qe_2 and qe_1 compared to the case of qe_3.

The estimated coefficient of inflation is positive and statistically significant. Quantitatively, it indicates that a 1% increase in the inflation rate leads to a rise in the 10-year bond yield by 13 to 16 basis points, depending on the regression specification, which suggests that investors seek to be compensated for holding long-term bonds when current inflation increases. The (cumulative) coefficient estimate for the output gap is consistently negative and statistically significant ranging from -0.08 to -0.09. Euro area output gap has been negative during 2003-2005 and also in deep negative territory during 2009-2016, bringing about an overall negative impact on bond yields which is also consistent with our theoretical framework in Brissimis and Georgiou (2022).

The constant term is estimated to be negative and significant, its value ranging between -1.06% and -1.61%. As already discussed in Section 4, the constant term is an important component of the monetary policy interest rate rule and is related to the

[16] Figure 4 depicts the actual values of the 10-year euro area government bond yield compared to its fitted values derived from estimating equation (4) when we employ the base money measure for quantitative easing, up to the end of our estimation period in 2019Q4. As already indicated, our model provides an excellent fit for the sample period; if, however, we extend the sample period to end-2023, in between 2020Q2 and 2021Q1 the forecasted yield shows a moderate decline reaching a low in the latter quarter, mostly related to the sharp contraction in real GDP due to the eruption of the COVID-19 pandemic crisis; the reduction also reflects the significant expansion of the base money that occurred at the same time as a result of the ECB's extraordinary quantitative easing programme and other monetary policy measures to mitigate the impact of the pandemic on the economy. The low point in 2021Q1 was subsequently reversed in the next quarters. Since 2022Q1, these disruptions in the forecasting value of the estimated equation seem to have been reduced and in the last few quarters, forecasted values got closer to actual ones.

exogenous equilibrium real interest rate. Its negative level overall indicates the low level of the natural rate recorded in the last decade as well as the effective lower bound constraint that became binding in the euro area in 2014.

Turning to the term premium component of bond yields, uncertainty is found to have a strongly positive and highly significant effect on the euro area bond yield as the respective coefficients are higher than or close to 1, ranging from 0.98 to 1.66. The magnitude of these coefficients shows that uncertainty in the euro area exerts a substantial impact on yields.[17] Quantitative easing of the Eurosystem is also estimated to have a negative and statistically significant effect on long-term rates; this effect is of a higher magnitude in the case of qe_2, i.e., the reserves and banknotes-to-GDP ratio. Quantitatively, coefficient estimates imply that a 1 per cent increase in qe_1, qe_2, qe_3, leads to a decline in bond yields of 69, 75 or 29 basis points, respectively.

[Insert Table 6 here]

The coefficient of the underlying time trend in the path of the bond yield is also found to be negative and highly significant, its effect ranging from $-5.33*10^{-3}$ to $-6.22*10^{-3}$. This effect suggests that there are time periods when interest rates adjust to varying trends, as had been the case in the euro area following the debt crisis, which brought about fundamental changes in factors outside the control of the central bank that significantly accelerated the declining path in interest rates.

The specification of our model supports the view that the long-term interest rate adjusts gradually to its long-run level allowing us to estimate both short-run and long-run (cumulative) effects of the qe variables on the bond yield. Short-run effects are given directly by estimated coefficients of the qe variables in Table 6, while long-run effects are further derived by dividing the short-run coefficients by the speed of adjustment parameter (δ). Long-run effects imply that if an increase in the respective qe ratio is made permanent, i.e., if it is sustained in the long run, e.g., by means of recurring re-investments or recurring unconventional refinancing operations, then it

[17] Carpenter et al. (2021) have studied bond risk premia as a function of risk, decomposing them in two components, namely the quantity of risk (uncertainty) and the price of that risk (Sharpe ratio) which both vary over time. Unlike this approach, our paper uses the CISS index as a proxy for uncertainty which implicitly assumes that the quantity of risk is allowed to vary, while the price of risk is constant over time. In the case of our estimations, the results of the CUSUM of squares test, which is used to assess the stability of a model's parameters over time, are suggestive of parameter constancy during the sample period.

will eventually result in a cumulative downward effect on yields of a considerably higher magnitude. Table 7 makes a comparative presentation of short-run and long-run effects of qe_1, qe_2 and qe_3. In the case of qe_1, the long-run effect of a 1% sustained (permanent) increase would reach 257 basis points. In the case of qe_2, the long-run effect seems to be even stronger at 300 basis points while in the last case of qe_3 it stands lower at 156 basis points.

[Insert Table 7 here]

During the period under examination 1999-2019, the unconventional monetary policy of the Eurosystem could be further distinguished in three sub-periods: (i) one of moderate balance sheet expansion (conducted mainly through unconventional refinancing operations with full allotment) lasting from 2008Q3 to 2014Q3, (ii) a second one of a massive balance sheet expansion mainly on account of the public sector asset purchase programme lasting from 2014Q4 up to 2018Q4, and (iii) a third one of short duration from 2019Q1 to 2019Q3 when the Eurosystem made only re-investments in maturing securities holdings.

Based on the above estimated coefficients, Table 8 provides a quantitative assessment of the effects of realized changes in qe_1 and qe_2 on the long-term interest rate. In detail, it is estimated that the € 290 bn rise in base money during 2008Q3-2014Q3, i.e., from 9.3% of GDP to 11.7%, brought about a reduction in euro area bond yields by 16 basis points. During the period of strong Eurosystem balance sheet expansion (2014Q4-2018Q4), base money in the euro area rose by almost € 2 trillion to reach 27.7% of euro area GDP; this unprecedented increase was translated into a further 59 basis points reduction in bond yields. During 2019, base money remained broadly stable at € 3.2 trillion, and the reinvestment policy was associated with a marginal rise of 4 basis points in bond yields.

[Insert Table 8 here]

Regarding qe_2 (i.e., the reserves and banknotes in circulation-to-GDP ratio) the realized increase by € 258 billion in the first period of moderate balance sheet expansion, is shown to be related to a 15-basis points reduction in euro area bond yields, while in the second period of interest, the € 1400 billion rise in reserves and banknotes in circulation (from 11% to around 22% of GDP) led to a 49 basis points reduction in yields. During the reinvestments-only period, the evolution of qe_2 related to a marginal rise of 2 basis points in bond yields.

In the case of qe_3 (i.e. reserves-to-GDP-ratio) bank reserves with the Eurosystem remained broadly stable at 2.2% of GDP in the first period under examination and this was associated with a marginal rise of 4 basis points in yields. During 2014Q4-2018Q4, reserves rose by € 1.2 trillion to reach almost 12% of GDP, an increase that brought about a 53 basis points decline in interest rates, while during the reinvestment-only period, this ratio was associated with a marginal increase of 2 basis points in yields.

The respective estimated long-run effects point to overall substantial reductions in euro area bond yields standing at around 60 basis points in 2008Q3-2014Q3 in the case of qe_1 and qe_2, while the effect based on qe_3 suggests a mild increase of 21 basis points. Longer-run declines in yields ranged from 199 to 285 basis points for the alternative qe measures during 2014Q4-2018Q4, while for the reinvestments-only period the rise in yields is estimated between 7 and 13 basis points.

According to the preceding discussion in Section 5.1 regarding the stationarity properties of the qe series, it could be assumed that these series are trend stationary with a breakpoint around mid-2012 or early-2013, when, following the unconventional three-year LTROs conducted by the Eurosystem, these stock variables rose exceptionally relative to their prior levels, before starting to rise even more persistently in 2014. It could be the case that after these breakpoints, a change in the effect of qe on interest rates could have taken place. For this reason, we have run additional regressions to detect variations in the coefficients of qe. To this end, we have included appropriate interaction terms of the qe variables with a dummy: (i) for the period from the breakpoint date of each qe variable in 2012/early 2013 until the end of the sample; this period broadly coincides with the time when the deposit facility rate was reduced to zero and subsequently moved toward its effective lower bound, and (ii) for the period of implementation of the negative interest rate policy (NIRP) of the Eurosystem starting in mid-2014 onward. The results for each qe measure are presented in Table 9 (columns b and c) along with initial results (column a). It is worth noting that the estimated coefficient on the multiplicative term associated with the period after mid-2012 remains insignificant in all cases, suggesting the absence of a discernible change in the systematic response of the long-term interest rate to this variable compared to the period before this date. In the case of the NIRP period though, the differential effect of qe increases as it is found to be positive and statistically significant under all three alternative definitions of qe. This means that its overall negative effect on the long-term rate weakens significantly to -0.48, -0.52 and -0.17 for qe_1, qe_2 and qe_3 respectively. The weakening of the qe effect during the implementation of the NIRP could be suggestive of the side- or counterproductive effects of this policy stemming for example from a negative impact on bank profitability due to the high amount of reserves in the banking system (that received a negative remuneration) or due to increased holdings of cash from economic agents or banks, implying less stimulus provided to investment, consumption and economic activity in general than initially intended by monetary policy.

[Insert Table 9 here]

6. Conclusions

In this paper, we follow the macro-finance framework developed in Brissimis and Georgiou (2022) −which has initially been applied to the US− to also study the behavior of long-term interest rates in the euro area. In this context, the model of the Expectations Hypothesis is effectively employed to relate expectations of future short-term rates to macroeconomic variables through an interest rate rule, which describes monetary policy in its conventional form, while unconventional monetary policy is a main determinant of the term premium component of the long-term rate.

From a macroeconomic perspective, empirical results verify that current inflation and the output gap are important factors in interpreting expectations of future short-term interest rates. The negative constant term is consistent with the broader decline in the equilibrium real interest rate recorded over the past decades, while a declining path of the long-term interest rate is confirmed in our specification since the peak of the debt crisis in the euro area and the few years that followed.

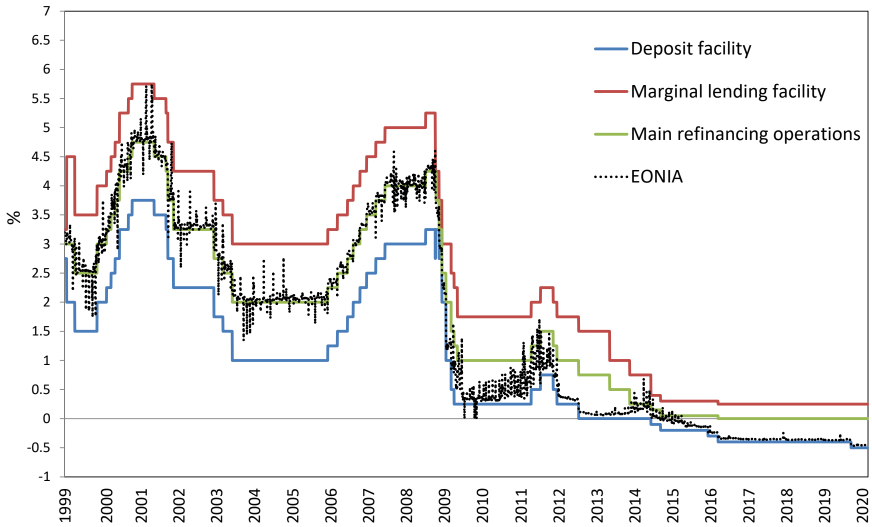
To assess monetary easing effects on the long-term interest rate, we exploit alternative stock measures from the liabilities side of the Eurosystem balance sheet which encompass large expansions in base money or central bank reserves during the various phases of unconventional policy implementation. Apart from short-run effects, we also provide estimates for long-run effects of monetary easing resulting from sustained (permanent) increases in central bank liabilities. According to our estimates, a one-unit rise in the corresponding qe-to-gdp ratio −in terms of base money, or banks' reserves with the Eurosystem plus currency in circulation, or solely banks' reserves with the Eurosystem− should reduce the euro area 10-year government bond yield by 69, 75 or 29 basis points respectively; if the increase is sustained in the long run, it is estimated that the decline would reach up to 257, 300 or 156 basis points in each case. The two broader measures of monetary easing imply overall an effect of higher magnitude as compared to banks' reserves with the Eurosystem. Based on these estimates, realized rises in Eurosystem liabilities relate to a reduction of 16, 15, or a marginal rise of 4 bps respectively during the initial phase of moderate Eurosystem balance sheet expansion, a further decline of 59, 49 or 53 bps respectively during the period of massive balance sheet expansion, that subsequently was only marginally reversed during the very short reinvestment-only period in 2019.

Further estimations of a potentially differential impact of monetary easing on bond yields during the zero or negative interest rate period provide evidence that during the implementation of the negative interest rate policy, the effects of monetary easing may have been weakened compared to those in the broader period under examination. These observations suggest that a better understanding of market structures, balance sheet adjustments and preferences of banks and other market participants may be required for a more accurate assessment of the mechanisms through which unconventional monetary easing is transmitted to the real economy.

Figures and Tables

Figure 1

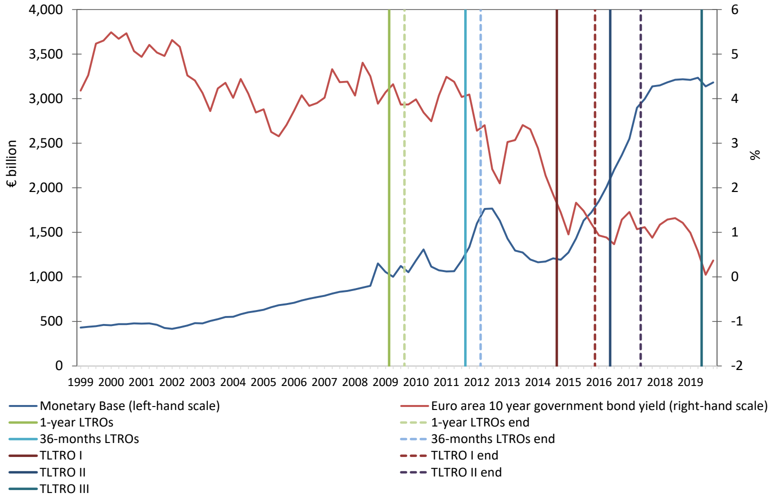
Eurosystem policy rates and euro overnight money market rates (January 1999-February 2020)



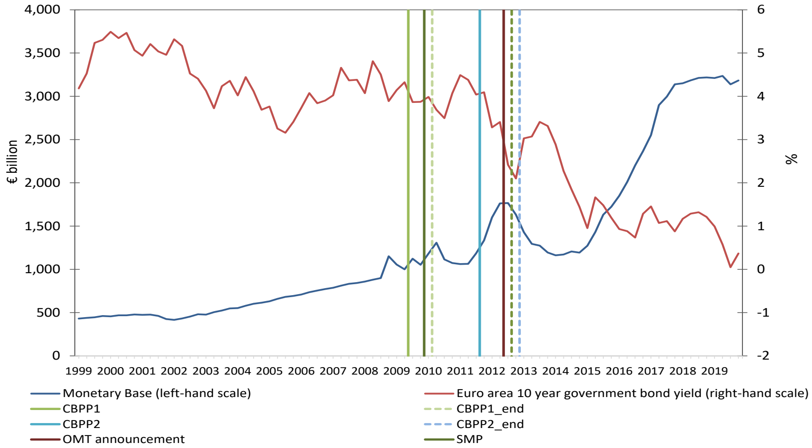
Sources: European Central Bank and European Money Markets Institute.

Figure 2

Base money (bn €), Euro area 10-year government bond yield (%) and unconventional Eurosystem longer-term refinancing operations



Base money (bn €), Euro area 10-year government bond yield (%) and initial Eurosystem asset purchase programs



Base money (bn €), Euro area 10-year government bond yield (%) and the Eurosystem expanded asset purchase program (APP)

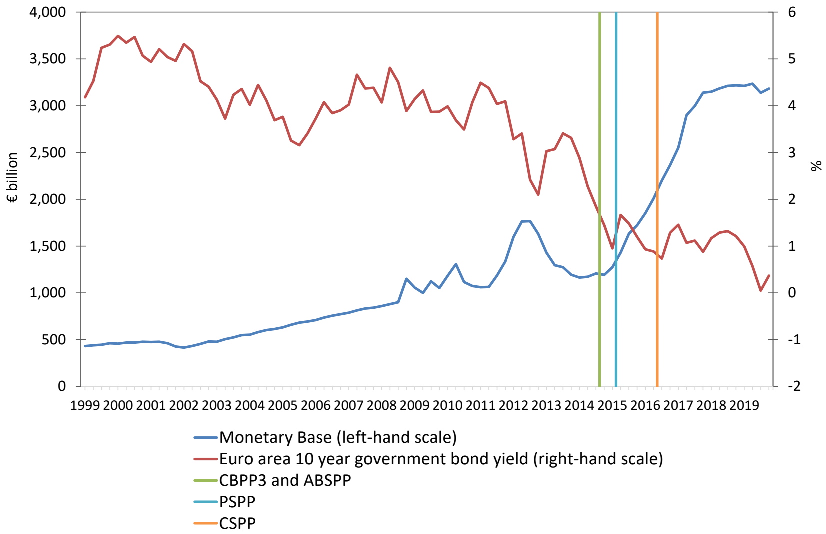


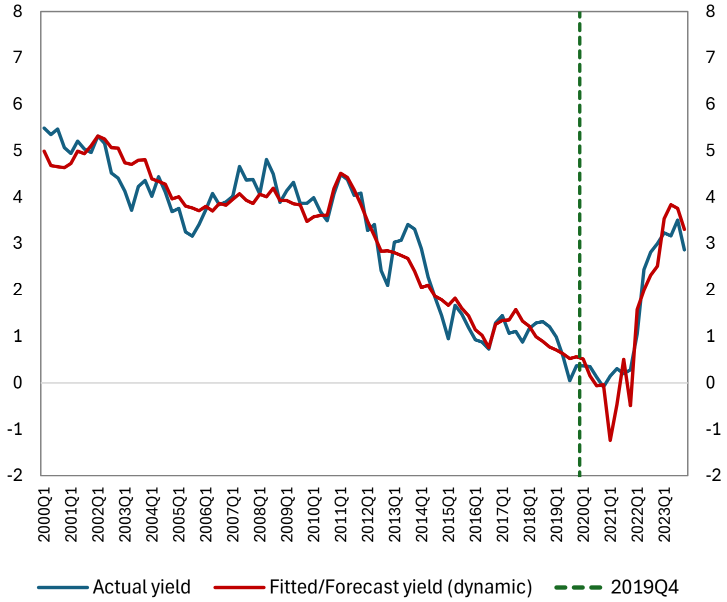
Figure 3.A-E

Diagrammatic representation of main variables

Figure 4

10-year euro area bond yield: actual and forecast values

(%)



Source: European Central Bank and own estimates.

Table 1
Non-standard refinancing operations of the Eurosystem (2007-2019)

Operation	**Maturity**	**Size**	**Start** (first operation)	**End** (last operation)
Longer-term refinancing operations (LTROs)				
Supplementary LTROs	3 months 6 months		Aug. 2007 Apr. 2008	Nov. 2013 Apr. 2010
Special-term refinancing operations	One maintenance period		Sept. 2008	Mar. 2010
LTROs	1 year	€ 442 bn € 75 bn € 96 bn	June 2009 Sept. 2009 Dec. 2009	
LTROs	36 months	€ 489 bn € 530 bn	Dec.2011 Feb.2012	
Targeted longer-term refinancing operations (TLTROs)	TLTRO-I : up to 4 years TLTRO-II: up to 4 years TLTRO-III: up to 3 years	€ 425 bn € 740 bn € 105 bn (up to end-2019)	Sept.2014 June 2016 Sept. 2019	Mar.2016 Mar.2017 Dec.2021

Source: European Central Bank.

Table 2

Chronology of the Eurosystem's asset purchase programmes (2009-2019)

Programme	Type of assets	Size	Start	End
1st covered bond purchase programme (CBPP1)	Euro-denominated covered bonds (primary and secondary markets)	€ 60 bn	July 2009	June 2010
Securities Market Programme (SMP) (sterilized)	Euro area public and private debt securities (secondary market)	Not defined in advance	May 2010	Sept.2012
2nd covered bond purchase programme (CBPP2)	Euro-denominated covered bonds (primary and secondary markets)	€ 40 bn (intended amount) € 16.4 bn (final amount)	Nov. 2011	Oct. 2012
Outright Monetary Transactions (OMT) (intended to be sterilized)	Sovereign bonds of Member States under an appropriate EFSF/ESM programme with a maturity of 1 to 3 years	No ex ante quantitative limits	Announced in Aug. 2012	Not implemented up to now
Expanded asset purchase programme (APP):				
– Third covered bond purchase programme (CBPP3)	Euro-denominated covered bonds eligible according to the Eurosystem's collateral framework (primary and secondary markets)		Oct. 2014	Net purchases up to Dec.2018
– Asset-backed securities purchase programme (ABSPP)	Simple and transparent asset-backed securities (ABSs) issued by the private sector (primary and secondary markets)		Nov.2014	Net purchases up to Dec.2018
– Public sector purchase programme (PSPP)	Nominal and inflation-linked central government bonds, bonds issued by recognised agencies, regional and local governments, international organisations and multilateral development banks located in the euro area (secondary market)		Mar.2015	Net purchases up to Dec.2018
– Corporate sector purchase programme (CSPP)	Investment-grade euro-denominated bonds issued by non-bank corporations established in the euro area (primary and secondary markets, but no primary market purchases involving debt instruments issued by entities that qualify as public undertakings)		June 2016	Net purchases up to Dec.2018
Reinvestments (in full) of principal payments of maturing securities purchased under APP			Dec.2015	*Cont. after end-2019*

Combined net asset purchases under CBPP3, ABSPP, PSPP, CSPP per month		€60 billion	Mar.2015	Mar.2016
		€80 billion	Apr.2016	Mar.2017
		€60 billion	Apr. 2017	Dec.2017
		€30 billion	Jan. 2018	Sept.2018
		€15 billion	Oct. 2018	Dec.2018
Conclusion of net purchases, only reinvestments (in full) of principal payments of maturing securities purchased under APP			Jan.2019	Oct.2019
Combined net purchases under CBPP3, ABSPP, PSPP, CSPP per month		€ 20 bn	Nov. 2019	*Cont. after end-2019*

Source: European Central Bank.

Table 3

Definition of variables

Variable	Notation	Measure	Data source
Long-term interest rate	i	Euro area 10-year government benchmark bond yield (%)	ECB
Inflation rate (annualized)	π	Difference in the GDP deflator (in log, %) between two successive quarters	Eurostat
Output gap	x	Difference between real GDP and real potential GDP (in logs, %)	Eurostat, Ameco database
Uncertainty (square root)	*unc*	Composite Indicator of Systemic Stress (CISS)	ECB
Quantitative easing (as a percent of nominal GDP, in logs)	qe_i $i=1,2,3$	1) Base money 2) Total reserves of credit institutions with the Eurosystem and banknotes in circulation 3) Total reserves of credit institutions with the Eurosystem	ECB, Eurostat

Table 4

Descriptive statistics (1999Q1-2019Q4)

	i	*π*	*x*	qe_1	qe_2	qe_3	*unc*
Mean	3.31	1.55	-0.61	-2.18	-2.27	-3.59	0.18
Std. Dev.	1.51	0.81	1.75	0.49	0.41	0.69	0.16
Median	3.85	1.56	-0.45	-2.21	-2.28	-3.87	0.11
Maximum	5.49	3.41	2.41	-1.27	-1.42	-1.98	0.79
Minimum	0.05	-0.68	-3.73	-2.86	-2.88	-4.43	0.02
Observations	84	84	84	84	84	84	84

Table 5A

ADF-test results

Variable \ ADF statistic	H_1: the series is stationary	H_1: the series is stationary around a constant term	H_1: the series is stationary around a constant and a trend
i	-3.28 ***	-2.41	-3.54 ***
π	-0.44	-3.60 ***	-4.13 ***
x	-2.03 **	-2.15	-2.23
unc	-2.34 **	-3.52 ***	-3.53 ***
qe_1	-1.93 *	0.18	-2.97
qe_2	-2.70 ***	0.99	-2.34
qe_3	-1.35	-0.04	-1.68

Notes: The null hypothesis H_0 in all tests is that the series has a unit root. The alternative hypothesis H_1 is quoted respectively in the three different forms of the test.
*, **, *** denote statistical significance at the 10%, 5% and 1% level respectively.
qe_1, qe_2, qe_3 refer to the alternative stock variables (base money, banks' reserves and banknotes in circulation, and banks' reserves respectively) used to proxy the central bank balance sheet and not to separate asset purchase programmes. For the exact definition of variables see Table 3.

Table 5B

ADF-test results (with a breakpoint)

Variable (breakpoint date) \ ADF statistic	H_1: the series is stationary around a constant term with a breakpoint in the constant term	H_1: the series is trend stationary with a breakpoint in the constant term	H_1: the series is stationary around a trend with a breakpoint in the trend	H_1: the series is stationary around a trend with a breakpoint in the constant term and the trend
qe_1 (2012 Q2)	-1.70	-3.84	-3.29	-4.97 *
qe_2 (2012 Q3)	-1.50	-3.85	-3.72	-7.61 ***
qe_3 (2016 Q1, 2014 Q3, 2013 Q1)	-3.98	-5.10 **	-5.31 ***	-8.36 ***

Notes: The null hypothesis H_0 in all tests is that the series has a unit root. The alternative hypothesis H_1 is quoted respectively in the three different forms of the test.
*, **, *** denote statistical significance at the 10%, 5% and 1% level respectively.
qe_1, qe_2, qe_3 refer to the alternative stock variables (base money, banks' reserves and banknotes in circulation, and banks' reserves respectively) used to proxy the central bank balance sheet and not to separate asset purchase programmes. For the exact definition of variables see Table 3.

Table 6 Estimation results

	OLS		
	(1)	(2)	(3)
c_0	-1.48*** (0.33)	-1.61*** (0.45)	-1.06*** (0.33)
π_{t-1}	0.13** (0.06)	0.13** (0.06)	0.16** (0.06)
$\sum_{s=1}^{4} x_{t-s}$	-0.09** (0.04)	-0.09* (0.05)	-0.08* (0.04)
$\sum_{s=1}^{4} unc_{t-s}$	1.66*** (0.41)	1.37*** (0.39)	0.98*** (0.36)
$qe_{1,t}$	-0.69*** (0.21)		
$qe_{2,t}$		-0.75** (0.30)	
$qe_{3,t}$			-0.29** (0.16)
i_{t-1}	0.73*** (0.07)	0.75*** (0.08)	0.81*** (0.09)
t	$-5.33*10^{-3}$*** ($1.50*10^{-3}$)	$-5.39*10^{-3}$*** ($1.72*10^{-3}$)	$-6.22*10^{-3}$*** ($1.72*10^{-3}$)
Observations	80	80	80
R-squared	0.96	0.96	0.95
Standard errors	HAC	HAC	HAC
Breusch-Godfrey LM test:			
AR(1)	0.81	0.90	0.70
AR(2)	0.97	0.95	0.88
AR(3)	0.99	0.98	0.96

Notes: Dependent variable is the 10-year government bond yield; (*), (**), (***) denote significance at the 10%, 5% and 1% level, respectively. Standard errors are reported in parentheses. The Breusch-Godfrey LM test tests for no autocorrelation (null) for AR(1) to AR(3) (p-value).
qe_1, qe_2, qe_3 refer to the alternative stock variables (base money, banks' reserves and banknotes in circulation, and banks' reserves respectively) used to proxy the central bank balance sheet and not to separate asset purchase programmes. For the exact definition of variables see Table 3.

Table 7

Short-run and long-run effects of Eurosystem's quantitative easing on the long-term interest rate

(basis points, per unit increase in the respective qe ratio)

	Short-run effect	Long-run effect
qe_1	-69	-257
qe_2	-75	-300
qe_3	-29	-156

Notes: qe_1, qe_2, qe_3 refer to the alternative stock variables (base money, banks' reserves and banknotes in circulation, and banks' reserves respectively) used to proxy the central bank balance sheet and not to separate asset purchase programmes. For the exact definition of variables see Table 3.

Table 8
Total effect of the Eurosystem balance sheet policy on the long-term interest rate during different phases of policy implementation
(basis points)

	Balance sheet expansion (FRFA/TLTRO) 2008Q3-2014Q3		Balance sheet expansion (APP/TLTRO) 2014Q4-2018Q4		Reinvestments only 2019Q1-2019Q3	
	Short-run effect	Long-run effect	Short-run effect	Long-run effect	Short-run effect	Long-run effect
qe_1	-16	-60	-59	-221	4	13
qe_2	-15	-62	-49	-199	2	7
qe_3	4	21	-53	-285	2	10

Notes: qe_1, qe_2, qe_3 refer to the alternative stock variables (base money, banks' reserves and banknotes in circulation, and banks' reserves respectively) used to proxy the central bank balance sheet and not to separate asset purchase programmes. For the exact definition of variables see Table 3.

Table 9 - Estimation results for the differential impact of qe

	qe_1 (base money-to-GDP)			qe_2 (reserves and banknotes-to-GDP)			qe_3 (reserves-to-GDP)		
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
c_0	-1.48*** (0.33)	-1.36*** (0.39)	-1.00*** (0.33)	-1.61*** (0.45)	-1.47*** (0.52)	-1.12*** (0.34)	-1.06*** (0.33)	-1.36** (0.54)	-0.63* (0.34)
π_{t-1}	0.13** (0.06)	0.13** (0.06)	0.12** (0.07)	0.13** (0.06)	0.13** (0.06)	0.12* (0.06)	0.16** (0.06)	0.16** (0.06)	0.16** (0.06)
$\sum_{s=1}^{4} x_{t-s}$	-0.09** (0.04)	-0.09** (0.04)	-0.09** (0.04)	-0.09** (0.05)	-0.08* (0.05)	-0.08* (0.05)	-0.08* (0.04)	-0.08* (0.04)	-0.08** (0.04)
$\sum_{s=1}^{4} unc_{t-s}$	1.66*** (0.41)	1.59*** (0.44)	1.39*** (0.42)	1.37*** (0.39)	1.31*** (0.42)	1.08*** (0.44)	0.98*** (0.36)	1.20** (0.46)	0.84** (0.46)
$qe_{i,t}$	-0.69*** (0.21)	-0.68*** (0.21)	-0.75*** (0.19)	-0.75** (0.30)	-0.71** (0.30)	-0.76*** (0.29)	-0.29** (0.16)	-0.33* (0.17)	-0.31** (0.15)
$qe_{i,t} * d_{12q3\_19q4}$		0.06 (0.12)			0.04 (0.10)			-0.06 (0.08)	
$qe_{i,t} * d_{14q2\_19q4}$			0.27*** (0.09)			0.24** (0.10)			0.13** (0.06)
i_{t-1}	0.73*** (0.07)	0.72*** (0.09)	0.62*** (0.08)	0.75*** (0.08)	0.76*** (0.09)	0.65*** (0.9)	0.81*** (0.09)	0.83*** (0.08)	0.73*** (0.10)
$trend$	$-5.33*10^{-3}$*** ($1.50*10^{-3}$)	$-4.63*10^{-3}$*** ($1.24*10^{-3}$)	$-4.51*10^{-3}$*** ($1.35*10^{-3}$)	$-5.39*10^{-3}$*** ($1.72*10^{-3}$)	$-4.88*10^{-3}$*** ($1.57*10^{-3}$)	$-4.80*10^{-3}$*** ($1.80*10^{-3}$)	$-6.22*10^{-3}$*** ($1.72*10^{-3}$)	$-7.55*10^{-3}$*** ($2.00*10^{-3}$)	$-5.42*10^{-3}$*** ($1.77*10^{-3}$)
Observations	80	80	80	80	80	80	80	80	80
R-squared	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Standard errors	HAC	HAC	HAC	HAC	HAC	HAC	HAC	HAC	HAC
Tests									
Breusch-Godfrey LM Test:									
for AR(1)	0.81	0.96	0.94	0.90	0.99	0.76	0.70	0.58	0.97
for AR(2)	0.97	0.97	0.99	0.95	0.93	0.85	0.88	0.81	0.84
for AR(3)	0.99	0.99	0.98	0.98	0.97	0.83	0.96	0.91	0.93

Notes: Dependent variable is the 10-year government bond yield; (*), (**), (***) denote significance at the 10%, 5% and 1% level, respectively. Standard errors are reported in parentheses. The Breusch-Godfrey LM test for AR(1) to AR(3) (p-value) tests for no autocorrelation (null).

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